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TERRAIN CHARACTERISTICS AT DIRT-I TEST SITE, WHITE SANDS MISSILE RANGE NEW MEXICO

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The study reported herein was conducted to characterize the terrain conditions prior to and during the conduct of the DIRT-I Test Program sponsored and directed by the U. S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico. The DIRT-I Test Program was conducted to investigate methods of directly sensing the properties of explosion-generated dust clouds and to make a series of transmission comparisons through the explosions. The specific cont

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20. ABSTRACT (Continued).

Co~ objective of the study reported herein was to obtain a correlative set of data concerning ambient soil characteristics (with depth), explosive forces induced and geometry of craters produced by the explosive forces.

Field measurements were made before and during the conduct of static- and artillery-delivered explosive detonations. The measurements included the collection of specific soil property crater geometry values throughout the site (impact area). These soil parameters included: size distribution, soil moisture content, soil density, organic material, soil strength, and crater size.

Ultimately, this analysis will be used for several purposes such as relationship of particle size and density to observed attenuation of electromagnetic propagation throughout the dust cloud; correlation of cloud particle size measurements with soil samples; relationship of crater volume to charge size; diffusion and dispersion of dust and smoke; and other measurements critical to battlefield dust modeling. Results will also be used to design future tests.

PREFACE

This study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Electronics Research and Development Command, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, under Intra-Army Order No. W43P6S78-8146. The field data were collected during the conduct of the DIRT-I, dust cloud measurement tests, at White Sands Missile Range, New Mexico.

The work was conducted during the period September to November 1978. This work was under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory, Mr. B. O. Benn, Chief, Environmental Systems Division (ESD), and Dr. L. E. Link, Chief, Environmental Constraints Group (ECG). Project manager was Mr. J. R. Lundien, ESD. Project leader was Mr. C. A. Miller, ECG. Mr. J. B. Mason, ECG, assisted in the tabulation and analysis of the field data in preparation for this report. This report was written by Mr. Miller.

Commander and Director of WES during this work and preparation of this report was COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

TERRAIN CHARACTERISTICS AT DIRT-I TEST SITE
WHITE SANDS MISSILE RANGE, NEW MEXICO

PART I: INTRODUCTION

Background

1. The performance of electro-optical devices can be severely degraded by the presence of obscurants in the atmosphere. This constraint on performance must be considered in the design and evaluation of such devices to ensure that they will operate effectively in realistic battlefield conditions. The amount and character of obscurants in the atmosphere is a function of the terrain conditions, sources of disturbance, and climatic conditions.

2. The terrain is the source of the raw materials that become atmospheric obscurants. Since terrain conditions vary immensely at times on both a local and regional scale it is important to quantify the impact of terrain conditions such as surface geometry, vegetation cover, and geologic materials on the extent and character of the obscurants placed in the atmosphere from the variety of possible disturbances that could occur on the battlefield and under the spectrum of possible climatic conditions.

3. Climatic conditions can have a two-fold effect. First, the antecedent climatic (weather) conditions have an impact on the state-of-the-ground. It is fairly safe to hypothesize that the character of material thrown into the air by an artillery burst would differ considerably for a wet plowed field and a very dry bare soil area. Secondly, the climatic conditions can significantly impact on the distribution (temporal and areal) of obscurants in the atmosphere. A dust cloud created by an artillery burst will disperse more quickly on a windy day than on a calm day for similar terrain conditions.

4. Field test progress to investigate the duration, extent, and optical attenuation characteristics of debris clouds resulting from terrain surface disturbances requires that the measurements and observations of the debris clouds be supplemented with equally detailed

characterization of terrain conditions, the specific forces induced by the method of disturbance (such as vehicle movement, explosive charges, or artillery bursts) and climatic conditions prior to and during the tests. Only with this complete data set can meaningful relationships be derived for model formulation or extrapolation of test results be made to other terrain, disturbance, or climatic conditions.

Purpose and Scope

5. The purpose of the work reported herein was to characterize the terrain conditions prior to and during the conduct of the DIRT I test program sponsored and directed by the U. S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico. The test site was a relatively flat area on the White Sands Missile Range installation. Prior to the tests all major surface irregularities and vegetation were removed from the test area by blading with a bulldozer. The normal approach for terrain characterization is to quantify surface geometry, surface vegetation cover, and the character of surface and subsurface geologic materials. The blading of the test area precluded the need to document surface geometry and vegetation conditions for this particular test program. As such, a majority of resources expended were focused on characterizing the surface and subsurface geologic materials.

6. Specifically the objective was to obtain a correlative set of data concerning ambient soil characteristics (with depth), explosive forces induced, and geometry of craters produced by the explosive forces. The crater geometry data were desired to provide an estimate of the volume of material injected into the atmosphere and to judge the impact of any variations in soil properties within the site on the volume of materials injected into the atmosphere.

7. Field measurements were made prior to and during the conduct of static- and artillery-delivered explosive detonations. The measurements included the collection of specific soil property crater geometry values throughout the site (impact area). In the data tables and diagrams

presented in the back of this document the alphanumeric symbols "A, B, C, D, and E" are used to identify specific subtests within the overall test series as follows:

Symbol	Date	Description
A	20 Oct 78	Graded explosive charges
B	30 Oct 78	Graded charges
C, 2C	5 Oct, 10 Oct 78	Large area
D	6 Oct 78	Graded charges
E	11 Oct, 14 Oct 78	155-mm rounds, static detonation
F	12 Oct 78	Live 155-mm howitzer firings

8. This document describes the data collection efforts by the U. S. Army Engineer Waterways Experiment Station personnel during the DIRT I tests, presents the data collected, and provides a limited discussion of those data.

PART II: DATA COLLECTION PROGRAM

Types of Data Collected

9. The following types of data were collected at selected locations to describe the characteristics at the DIRT I site:

- a. Soil descriptions according to the Unified Soil Classification System (USCS) and U. S. Department of Agriculture (USDA) plus specific gravity and organic content.
- b. Soil moisture content.
- c. Soil density.
- d. Soil strength in terms of cone index (CI) to a depth of 45 cm.
- e. Crater geometry including apparent radius and apparent depth (see Figure 1).

Data Collection Procedures

10. The data described in the previous paragraph were collected in essentially three parts. The first part consisted of soil measurements (a, b, c, and d in paragraph 9) taken prior to the conduct of the exercise. All preexercise measurements were made in the impact area at locations shown in Figure 2. The specific sample locations were selected by producing an overlay of the locations of all proposed static detonations and selecting points where concentrations of detonations would occur (Figure 3). A total of 26 sample locations (denoted as P1, P2, P3, ...etc.) were selected. Soil moisture and density measurements were made at the surface and at a depth of 30 cm at all sample locations. In addition, tests were conducted to a depth of approximately 85 cm where relatively large detonations were to be located. These locations are denoted as P13 through P18 in Figure 2.

11. The second portion of the data collection program consisted of measurements of crater geometry (apparent depth and apparent diameter at the surface) and soil moisture and soil strength (b, d, and e in paragraph 9) for specific craters throughout the impact area. Craters from the static tests (A, B, C, D, and E) were selected to allow for the

complete sampling of representative craters and crater arrays and also to account for possible changes in soil characteristics.

12. A more detailed procedure was used for the craters formed from the artillery impacted detonations (F test). A thorough search of the impact area was made in an attempt to locate and measure every artillery impacted crater within the impact area and within 25 meters of the area. Crater geometry data were collected for each crater and the approximate locations of the craters (denoted as F1, F2, F3, ...etc.) with respect to the center of the impact area were determined. The craters formed from impacted artillery had a characteristic elongated shape when compared to the statically detonated charges (Figure 4). For this reason measurements were made of both the major and minor axises of these craters. The crater locations were determined using standard surveying procedures for computation of bearing and distance by stadia. Time constraints did not allow for soil moisture and strength measurements at these craters. A total of 59 craters were located.

13. The final portion of the data collection program consisted of the acquisition of bulk samples for detailed laboratory analysis at WES. Samples were obtained to represent the material at a depth of 0-30 cm and 75-100 cm. The locations of the bulk samples (shown in Figure 5) were selected to include the spectrum of conditions in the impacted area. These samples were used to determine the grain-size distribution, specific gravity, organic content, and soil classification of the material.

PART III: PRESENTATION AND REVIEW OF DATA

Site Characteristics

Site description

14. The DIRT I site is located at the extreme southeast corner of the White Sands Missile Range. The center of the impact area is located at the grid coordinates x-555732 y-198016. The impact area is a rectangle with dimensions of 100 by 300 m with the long axis in an approximate northerly direction. Prior to the exercise, the vegetation had been removed from the impact area. A road extends along the center line of the area parallel to the long axis.

Soil characteristics

15. Generally, the soil in this area is a brown silty sand with intermittent pockets of coarse sand and rock fragments. The moisture content of this material is usually relatively low (less than 3 percent); however, numerous rainstorms in this area had caused the soil moisture to be abnormally high during the tests, especially within the first 75 cm of soil.

Site Characteristics Prior to Exercise

16. A compilation of the data collection conducted prior to the exercise is shown in Table 1. A schema of the locations of the sample points is shown in Figure 2. At each of the sample points, soil measurements were made which included moisture content, density, and cone index. These data indicate that, with the exception of the center line of the impact area, the soil conditions are relatively uniform throughout the impact area. The moisture content of the upper 15 cm of soil ranged from 2.3 to 13.2 percent with an average of 7.0 percent. The lowest moisture contents occurred at the outer perimeter of the impact area. The moisture contents of the 15-30 cm region ranged from 4.3 to 13.2 percent with an average of 9.8 percent. Deeper samples taken at P11, P12, P14, P15, P17, and P18 indicate that starting at a depth of

approximately 75 cm, a much dryer material is present having an average moisture content of 3.0 percent.

17. Soil density measurements taken at the "P" sample points (Table 1) indicate that the soil characteristics are relatively uniform with no specific trends for different areas within the impact area. The surface dry density varied from 1.45 to 1.83 g/cm^3 with an average of 1.63 g/cm^3 and the dry density of soil from 15 to 30 cm varied from 1.40 to 1.83 g/cm^3 with an average of 1.57 g/cm^3. The density and moisture data from this table indicate that the soil along the outer perimeter of the impact area had a tendency to be dryer and less dense than the average conditions for the site.

18. Figure 6 presents the results of a statistical analysis of the soil strength measurements (cone index) taken at the "P" sample points (Table 1) with the exception of those taken along the centerline road. These cone index values indicate the average shearing stress needed to displace the soil using a 30° cone having a maximum diameter of 1.3 cm. The vertical bars shown in the figure represent the range of cone index values of one standard deviation. These data indicate that the site is characterized by a loose surface layer of 5-10 cm thickness. Under this layer the cone index reaches a maximum value of 300 to 400 psi at 10 to 20 cm, below which it drops to values of 150 to 200. Averages of all the off-road cone index values for the layers 0-15 cm, 15-30 cm, and 30-45 cm were 239, 266, and 173, respectively. The strength characteristics of this site are similar to those found for cultivated areas. It is suspected that this characteristic may be the result of removing the surface vegetation with a bulldozer. The cone index data (Table 1) taken along the outer portion of the site indicate lower shear strength characteristics than the average. This corresponds with the trend in the soil density measurements described in paragraph 17.

19. The first 10 cm of the road surface along the center line of the impact area was exceptionally hard. Cone index values along the graded roadway were over 750 (the maximum cone index reading) for the first 10 cm. However, soil moisture and density values taken along this portion of the site indicate that the material under this surface crust

had essentially the same characteristics as the material adjacent to the road. Cone index measurements were not taken below the hard surface material.

Site and Crater Measurements During Exercise

20. Tables 2 to 8 and Figures 7 to 13 present a compilation and description of the location of crater geometry and soil characteristics measurements taken during the conduct of the static- and artillery-delivered detonation tests. The following paragraphs present a brief analysis of the data collected during these tests.

Soil characteristics data

21. Tables 2 through 8 present the soil characteristics data (moisture content and cone index) collected at selected crater locations each day after the conduct of tests. The cone index data were obtained adjacent to the outer edge of the ejecta portion of the crater tip (Figure 1). The average CI (cone index) for all tests at layer intervals of 0-15 cm, 15-30 cm, and 30-45 cm were 175, 212, and 161, respectively. When compared to the cone index data taken prior to the exercise (paragraph 18), these data indicate lower strength values. Since the cone index measurements taken during this portion of the work were made in close proximity of the craters, it is suspected these lower values can be partically attributed to the remolding of the soil due to the explosive detonation.

22. The moisture content samples were obtained by digging laterally into the sides of the selected craters as shown in Figure 14. Samples were taken at approximately one-half the depth and to the side of the crater. These data (Tables 2-8) indicate that the average moisture contents for the seven days of testing were 7.8, 6.5, 5.6, 5.8, 6.5, 5.6, and 5.8 percent, consecutively, with an overall average of 6.3 percent. This average moisture content is lower than that observed for the corresponding 15-30 cm depth average moisture contents measured prior to the exercise (Table 1). It is again suspected that the remolding of the soil during the formation of the crater caused the decrease in moisture content in the immediate vicinity of the craters.

Crater geometry results

23. Table 9 presents a summary of the crater measurements in which the means and standard deviations of the apparent crater depths and diameters are presented. This table also lists a volumetric factor represented by the product of apparent crater depth and the square of the apparent diameter. This quantity is assumed to be proportional to the volume of material available for atmospheric loading. Since the craters from the artillery-delivered detonations were characteristically elongated, the volumetric factors were computed using the square of the mean of the diameters. The test numbers in Table 9 [A(1), B(1), etc.] denote the individual series of multiple detonations conducted during each day of tests as described in the DIRT I test plan.

24. Figure 15 presents a comparison of volumetric factor ($d \times D^2$) and the size of the explosive charge for the statically emplaced and artillery-delivered denotations. The volumetric factors for the artillery rounds [Tests E(1) to E(4) and F] were plotted on the best-fit line of the preceeding static tests to indicate what static charge size would best represent the crater dimensions of the artillery-delivered rounds. These data indicate that for these test conditions artillery rounds statically detonated created craters larger than those resulting from artillery-delivered rounds of the same charge size.

Bulk Sample Measurements

25. Figures 16-24 show the results of sieve and hydrometer analysis of the bulk samples taken at locations shown in Figure 5. As indicated the material is silty sand under the USCS classification or loamy sand under the USDA. This material has an organic content of less than 2 percent.

26. The sand particle sizes observed are relatively fine as soils go with about 80 percent of the material by weight being smaller than 2.5-mm diameter. There is a significant fraction of material at sizes below .01 mm (10 μm). This is the silt and clay contribution and is most important to the atmospheric loading.

27. For purposes of reference, Figure 25, taken from G. P. Tschebotarioff, Soils Mechanics, Foundations and Earth Structures, McGraw-Hill, 1951, shows a number of measured soil distributions. The coarse fraction of the soil at White Sands most closely resembled curves 5 and 9 in Figure 25 which represents beach sands, and the fine fraction most closely resembled curves 3 and 4 in the figure which represent deltaic silts. The figure also illustrates the wide variety of soil size distributions that can occur in the same geographic region as indicated by curve 8 which represents New Mexico adobe brick.

PART IV: SUMMARY AND RECOMMENDATIONS

Summary

28. The DIRT-I test site may be characterized as uniform in composition and texture over the area and during the duration of the exercise. Characteristics the soil were as follows:

Type - Sand to silty sand

Organic content less than 2 percent

Average dry density - 1.60 gm/cc

Average wet density - 1.75 gm/cc

Average moisture content (0-15 cm) - 8.0 percent

Average moisture content (15-30 cm) - 10.2 percent

Average moisture content (30-45 cm) - 3.1 percent

Average cone index - 175

Plastic limit - 0 (nonplastic)

29. To add perspective to these parameters, the organic content range is low, the moisture content somewhat high for sand for this region (except at depth) and the cone index medium. Due to the alteration of the surface by bulldozing, the mechanical characteristics were somewhat similar to those of cultivated soil and not necessarily indicative of natural conditions.

30. The grain size distribution is typical of a fine, uniform sand. A silt, however, would have the distribution shifted roughly one order of magnitude toward smaller grains in addition to increasing the proportion of fines, and a clay would carry the same effect even further. The grain size measurements were similar for samples taken from the surface (0-10 cm) and 30-40 cm depth indicating a rather homogeneous material with depth.

31. Crater dimensions were documented and indicate a distinct correlation with explosive charge size. However, craters caused by artillery rounds statically placed at the surface proved much larger than those caused by the same size shell fired from tubes and fused for surface detonation.

Recommendations

32. The results of this study lead to the following recommendations:

a. A standardization of the data to be collected, the data collection procedures, the data analysis, and the presentation of results be formulated.

b. The collection of terrain characteristics and crater dimension data be continued during subsequent dust cloud field tests. These data should be collected based on the standard procedures.

c. The data bank formed from the standard measurements be used in the development of a mathematical model for predicting the particle size distribution and atmospheric loading caused by various munitions.

Table 1

Soil Characteristics, DIRT I Site

Sample Location	Depth (cm)	Moisture Content, %	Density Wet	Density Dry	Cone Index
P1	0-15	11.5	1.84	1.65	750+
	15-30	12.0	1.76	1.57	-
	30-45	-	-	-	-
P2	0-15	6.7	1.84	1.72	210
	15-30	9.6	1.77	1.61	280
	30-45	-	-	-	170
P3	0-15	7.4	1.82	1.69	285
	15-30	8.5	1.78	1.66	350
	30-45	-	-	-	150
P4	0-15	7.4	1.85	1.72	750+
	15-30	7.4	1.86	1.73	-
	30-45	-	-	-	-
P5	0-15	9.6	1.66	1.51	285
	15-30	9.6	1.67	1.83	460
	30-45	-	-	-	200
P6	0-15	9.6	1.73	1.58	180
	15-30	7.9	1.76	1.63	220
	30-45	-	-	-	150
P7	0-15	7.4	1.97	1.83	750+
	15-30	6.1	1.82	1.72	-
	30-45	-	-	-	-
P8	0-15	8.9	1.81	1.66	210
	15-30	8.9	1.66	1.52	230
	30-45	-	-	-	150
P9	0-15	7.4	1.67	1.56	175
	15-30	13.2	1.78	1.57	235
	30-45	-	-	-	150
P10	0-15	6.1	1.84	1.73	750+
	15-30	10.3	1.90	1.72	-
	30-45	-	-	-	-
P11	0-15	6.1	1.70	1.61	205
	15-30	13.2	1.75	1.55	370
	30-45	5.2*	-	-	260

(Continued)

Table 1 (Continued)

Sample Location	Depth (cm)	Moisture Content, %	Density Wet	Density Dry	Cone Index
P12	0-15	6.1	1.77	1.67	295
	15-30	13.2	1.65	1.46	210
	30-45	1.9*	-	-	165
P13	0-15	6.1	1.80	1.70	750+
	15-30	10.3	1.77	1.60	-
	30-45	-	-	-	-
P14	0-15	9.0	1.74	1.60	215
	15-30	13.9	1.63	1.43	195
	30-45	8.2*	-	-	165
P15	0-15	12.0	1.65	1.47	275
	15-30	12.6	1.68	1.50	295
	30-45	0.2*	-	-	175
P16	0-15	13.2	1.64	1.45	750+
	15-30	12.6	1.66	1.47	-
	30-45	-	-	-	-
P17	0-15	6.7	1.86	1.74	375
	15-30	12.0	1.65	1.48	245
	30-45	1.9*	-	-	150
P18	0-15	9.2	1.75	1.60	220
	15-30	10.3	1.76	1.60	270
	30-45	1.0*	-	-	190
P19	0-15	5.4	1.69	1.61	205
	15-30	8.7	1.61	1.48	215
	30-45	-	-	-	165
P20	0-15	3.2	1.75	1.70	240
	15-30	4.3	1.63	1.57	255
	30-45	-	-	-	170
P21	0-15	5.9	1.67	1.57	145
	15-30	10.7	1.60	1.44	170
	30-45	-	-	-	145
P22	0-15	4.5	1.66	1.59	220
	15-30	11.5	1.56	1.40	180
	30-45	-	-	-	150
P23	0-15	2.3	1.63	1.59	285
	15-30	5.0	1.61	1.53	245
	30-45	-	-	-	150

(Continued)

Table 1 (Concluded)

Sample Location	Depth (cm)	Moisture Content, %	Density Wet	Density Dry	Cone Index
P24	0-15	4.5	1.57	1.50	170
	15-30	8.7	1.67	1.54	210
	30-45	-	-	-	160
P25	0-15	2.7	1.64	1.60	240
	15-30	9.5	1.69	1.54	280
	30-45	-	-	-	190
P26	0-15	3.2	1.74	1.69	340
	15-30	5.4	1.64	1.55	405
	30-45	-	-	-	250

Table 2

Crater and Soil Characteristics for "A" Tests Conducted on 2 Oct 78

Crater Location	Apparent Depth (m)	Apparent Diameter (m)	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer, (cm) 0-15	15-30	30-37.5
A1	0.28	0.90	10.2	10-20	165	435	190
A2	0.23	0.75	4.5	10-15	750+	-	-
A3	0.30	0.90	9.4	15-25	140	215	150
A4	0.57	1.90	8.5	25-30	105	120	135
A5	0.46	1.60	9.2	25-30	750+	-	-
A6	0.57	1.75	6.8	25-30	115	275	155
A7	0.67	2.60	6.8	25-30	210	235	150
A8	0.60	1.80	9.2	25-30	750+	-	-
A9	0.67	2.30	9.2	25-30	165	170	150
A10	0.61	2.30	4.5	25-30	165	235	150
A11	0.57	2.00	4.5	25-30	750+	-	-
A12	0.62	2.40	10.7	25-30	135	220	180

Table 3

Crater and Soil Characteristics for "B" Tests Conducted on 3 Oct 78

Crater Location	Apparent Depth (m)	Apparent Diameter (m)	Moisture Content		Average CI at Layer, (cm)		
			Percent	Depth (cm)	0-15	15-30	30-37.5
B1	0.51	1.35	3.2	25-30	165	140	150
B2	0.40	1.45	3.8	25-30	750+	-	-
B3	0.56	1.50	8.9	25-30	190	345	150
B4	0.58	1.75	5.4	25-30	195	250	130
B5	0.61	2.00	6.3	25-30	750+	-	-
B6	0.59	2.20	8.4	25-30	205	270	150
B7	1.04	3.95	8.7 3.4	25-30 90-100	220	265	170
B8	0.99	3.60	6.8 2.7	25-30 75-80	750+	-	-
B9	0.83	4.10	9.7	25-30	150	155	150
B10	0.91	3.65	4.1 0.2	25-30 75-80	155	175	150
B11	0.88	3.85	9.4 0.2	25-30 75-80	750+	-	-
B12	1.09	4.10	3.8 1.6	25-30 75-80	180	205	150
B13	0.55	1.40	-	-	-	-	-
B14	0.55	1.35	-	-	-	-	-
B15	0.51	1.45	-	-	-	-	-
B16	0.61	1.95	-	-	-	-	-
B17	0.68	1.75	-	-	-	-	-
B18	0.57	1.85	-	-	-	-	-
B19	1.06	3.60	-	-	-	-	-
B20	0.83	3.10	-	-	-	-	-
B21	0.70	2.35	-	-	-	-	-
B22	0.90	3.30	-	-	-	-	-
B23	0.98	3.55	-	-	-	-	-
B24	1.19	4.15	-	-	-	-	-

Table 4

Crater and Soil Characteristics for "C" Test Conducted on 5 Oct 78

Crater Location	Apparent Depth (m)	Apparent Diameter (m)	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer, (cm) 0-15	15-30	30-37.5
C1	0.47	1.85	2.1	15-20	200	215	150
C2	0.53	1.50	4.7	15-20	165	170	150
C3	0.59	1.55	3.8	15-20	130	240	150
C4	0.55	1.50	2.7	15-20	750+	-	-
C5	0.63	1.80	8.2	15-20	165	215	150
C6	0.62	1.90	6.2	15-20	155	275	200
C7	0.55	1.70	9.5	15-20	260	385	245
C8	0.61	1.85	11.7	15-20	215	325	165
C9	0.56	1.60	6.3	15-20	195	215	150
C10	0.60	1.60	3.8	15-20	215	300	275
C11	0.56	1.85	7.3	15-20	175	190	150
C12	0.57	1.55	6.6	15-20	205	180	165
C13	0.60	1.40	2.1	15-20	750+	-	-
C14	0.56	1.70	4.1	15-20	165	190	150
C15	0.54	1.55	4.3	15-20	185	205	155
C16	0.63	1.60	5.9	15-20	145	140	150

Table 5

Crater and Soil Characteristics for "D" Test Conducted on 6 Oct 78

Crater Location	Apparent Depth (m)	Apparent Diameter (m)	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer, (cm) 0-15	15-30	30-37.5
D1	0.38	1.05	7.0	10-15	200	180	150
D2	0.38	1.05	4.1	10-15	750+	-	-
D3	0.39	1.00	6.3	10-15	165	215	150
D4	0.42	1.05	7.3	10-15	160	215	150
D5	0.32	1.05	7.7	10-15	750+	-	-
D6	0.54	1.35	7.5	10-15	185	210	180
D7	0.53	1.40	7.7	15-20	165	165	150
D8	0.54	1.40	4.7	15-20	750+	-	-
D9	0.49	1.67	3.2	15-20	140	225	160
D10	0.60	1.95	7.7	15-20	750+	-	-
D11	0.59	2.05	4.1	15-20	135	180	140
D12	0.53	2.00	3.2	15-20	155	165	180

Table 6

Crater and Soil Characteristics for "C" Test Conducted on 10 Oct 78

Crater Location	Apparent Depth (m)	Apparent Diameter (m)	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer, (cm) 0-15	Average CI at Layer, (cm) 15-30	Average CI at Layer, (cm) 30-37.5
2C- 1	.47	1.90	2.3	15-20	200	230	125
2C- 2	.50	1.65	5.7	15-20	150	165	125
2C- 3	.56	1.80	6.3	15-20	155	150	150
2C- 4	.59	1.65	2.3	15-20	750+	750+	750+
2C- 5	.62	1.85	4.5	15-20	165	155	150
2C- 6	.57	1.70	8.2	15-20	195	230	200
2C- 7	.48	1.80	11.2	15-20	210	290	200
2C- 8	.54	1.80	6.1	15-20	215	195	165
2C- 9	.65	1.75	7.3	15-20	200	230	180
2C-10	.51	1.65	8.4	15-20	125	140	140
2C-11	.48	1.70	8.4	15-20	155	185	160
2C-12	.59	1.70	8.2	15-20	165	190	200
2C-13	.52	1.75	7.0	15-20	750+	750+	750+
2C-14	.62	1.80	6.1	15-20	165	150	170
2C-15	.59	1.75	7.7	15-20	175	215	170
2C-16	.55	1.90	3.8	15-20	145	170	125

Table 7

Crater and Soil Characteristics for "E" Test Conducted on 11 Oct 78

Crater Location	Apparent Depth (m)	Apparent Diameter (m)	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer, (cm) 0-15	15-30	30-37.5
E- 1	.42	1.40	4.7	15-20	190	200	165
E- 2	.50	1.60	-	-	-	-	-
E- 3	.55	1.55	5.9	15-20	200	240	175
E- 4	.51	1.50	-	-	-	-	-
E- 5	.46	1.35	2.1	15-20	750+	-	-
E- 6	.49	1.35	-	-	-	-	-
E- 7	.52	1.35	7.8	15-20	305	305	190
E- 8	.44	1.45	-	-	-	-	-
E- 9	.52	1.50	2.3	15-20	165	150	150
E-10	.44	1.40	-	-	-	-	-
E-11	.53	1.35	6.3	15-20	750+	-	-
E-12	.67	1.40	-	-	-	-	-
E-13	.55	1.40	9.4	15-20	160	195	150
E-14	.50	1.45	-	-	-	-	-
E-15	.55	1.45	6.1	15-20	175	190	150
E-16	.51	1.45	-	-	-	-	-
E-17	.51	1.45	6.1	15-20	750+	-	-
E-18	.50	1.45	-	-	-	-	-

Table 8

Crater and Soil Characteristics for Artillery Impact Tests Conducted on 12 Oct 78

Crater Number	Crater Location[1] X	Crater Location[1] Y	Apparent Depth (m)	Apparent Diameter (m) Max	Apparent Diameter (m) Min	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer (cm) 0-15	Average CI at Layer (cm) 15-20	Average CI at Layer (cm) 30-37.5
F1	41.3	194.2	0.35	1.50	1.35	-	-	-	-	-
F2	41.0	169.5	0.35	1.60	1.35	-	-	-	-	-
F3	26.1	166.8	0.35	1.70	1.40	-	-	-	-	-
F4	39.9	163.8	0.35	1.60	1.40	-	-	-	-	-
F5	46.5	166.6	0.31	1.10	0.95	4.7	15-20	750+	-	-
F6	22.3	162.7	0.35	1.60	1.40	4.0	15-20	190	220	190
F7	18.8	148.1	0.28	1.30	1.20	-	-	-	-	-
F8	-58.2[2]	157.2	0.22	1.60	1.50	-	-	-	-	-
F9	-39.8[2]	177.8	0.18	1.60	1.50	5.6	15-20	155	150	150
F10	-33.6[2]	193.0	0.26	1.60	1.50	-	-	-	-	-
F11	37.5	145.7	0.36	1.45	1.40	-	-	-	-	-
F12	33.5	153.6	0.38	1.50	1.40	-	-	-	-	-
F13	28.1	156.3	0.31	1.45	1.45	-	-	-	-	-
F14	43.4	156.7	0.37	1.50	1.25	-	-	-	-	-
F15	40.3	151.7	0.38	1.65	1.35	-	-	-	-	-
F16	43.2	148.4	0.39	1.50	1.30	-	-	-	-	-
F17	42.8	148.4	0.39	1.30	1.25	-	-	-	-	-
F18	52.3	159.3	0.35	1.45	1.40	-	-	-	-	-
F19	63.1	149.2	0.33	1.60	1.30	6.3	15-20	185	175	1150
F20	69.2	157.1	0.41	1.45	1.30	-	-	-	-	-

(Continued)

Table 8 (Continued)

Crater Number	Crater Location[1] X	Crater Location[1] Y	Apparent Depth (m)	Apparent Diameter (m) Max	Apparent Diameter (m) Min	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer (cm) 0-15	Average CI at Layer (cm) 15-20	Average CI at Layer (cm) 30-37.5
F21	72.8	148.5	0.35	1.70	1.50	-	-	-	-	-
F22	57.9	142.5	0.40	1.70	1.45	-	-	-	-	-
F23	59.6	148.0	0.34	1.30	1.25	-	-	-	-	-
F24	121.6[2]	157.8	0.37	1.60	1.40	7.5	15-20	135	145	150
F25	86.5	163.6	0.35	1.70	1.45	-	-	-	-	-
F26	72.6	176.1	0.43	1.70	1.55	-	-	-	-	-
F27	83.8	130.6	0.47	1.60	1.45	-	-	-	-	-
F28	67.6	135.2	0.38	1.50	1.45	-	-	-	-	-
F29	46.0	137.3	0.44	1.60	1.40	-	-	-	-	-
F30	45.4	126.3	0.36	1.60	1.35	-	-	-	-	-
F31	51.4	129.0	0.48	1.50	1.35	-	-	-	-	-
F32	61.4	125.2	0.40	1.75	1.45	-	-	-	-	-
F33	64.1	125.3	0.38	1.45	1.40	-	-	-	-	-
F34	79.5	104.7	0.44	1.75	1.40	-	-	-	-	-
F35	28.9	115.9	0.37	1.65	1.45	-	-	-	-	-
F36	41.9	100.6	0.47	1.60	1.35	-	-	-	-	-
F37	62.5	72.2	0.43	1.70	1.40	-	-	-	-	-
F38	96.5	47.0	0.39	1.65	1.35	-	-	-	-	-
F39	113.9	66.7	0.16	1.70	1.40	-	-	-	-	-
F40	92.1	41.4	0.44	1.70	1.35	6.6	15-20	145	155	140

(Continued)

Table 8 (Concluded)

Crater Number	Crater Location[1] X	Crater Location[1] Y	Apparent Depth (m)	Apparent Diameter (m) Max	Apparent Diameter (m) Min	Moisture Content Percent	Moisture Content Depth (cm)	Average CI at Layer (cm) 0-15	Average CI at Layer (cm) 15-20	Average CI at Layer (cm) 30-37.5
F41	89.4	40.4	0.40	1.65	1.40	-	-	-	-	-
F42	38.8	31.5	0.38	1.65	1.35	-	-	-	-	-
F43	44.5	31.6	0.30	1.50	1.10	-	-	-	-	-
F44	67.0	32.2	0.39	1.40	1.35	-	-	-	-	-
F45	91.2	18.8	0.39	1.35	1.30	-	-	-	-	-
F46	26.3	142.0	0.48	1.50	1.40	-	-	-	-	-
F47	20.4	140.9	0.36	1.40	1.35	-	-	-	-	-
F48	11.8	117.8	0.34	1.70	1.40	-	-	-	-	-
F49	6.3	92.1	0.38	1.70	1.35	-	-	-	-	-
F50	37.3	103.2	0.42	1.60	1.35	-	-	-	-	-
F51	39.6	166.6	0.38	1.50	1.35	-	-	-	-	-
F52	50.4	70.0	0.35	1.40	1.30	-	-	-	-	-
F53	68.2	90.7	0.48	1.50	1.35	-	-	-	-	-
F54	71.1	88.7	0.45	1.40	1.40	-	-	-	-	-
F55	74.9	80.3	0.48	1.45	1.35	-	-	-	-	-
F56	44.6	136.9	0.35	1.70	1.30	-	-	-	-	-
F57	57.0	133.4	0.36	1.65	1.15	-	-	-	-	-
F58	47.6	112.1	0.30	1.45	1.45	-	-	-	-	-
F59	32.3	156.8	0.33	1.45	1.40	-	-	-	-	-

1 - These are the coordinates of the craters with respect to the southwest corner of the impact area.
2 - These craters are located outside of the impact area.

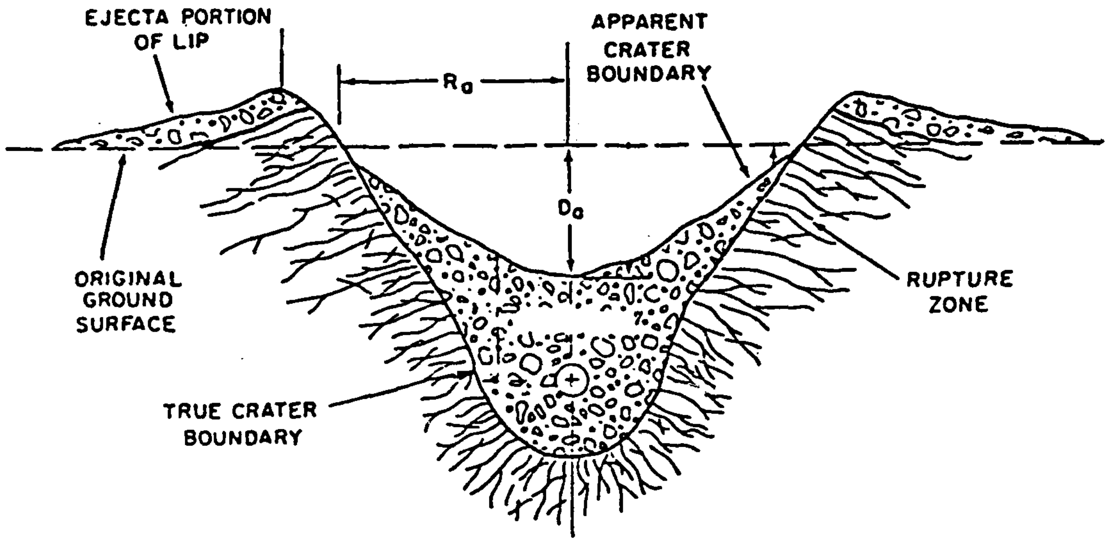
Table 9

Crater Measurements, Summary of Results

Event	Charge Size (kg)	Depth (d)	S_d*	Diameter (D)	S_D*	$d \times D^2$
A-1	.45	0.27	0.04	0.85	0.09	0.20
A-2	6.8	0.53	0.06	1.75	0.15	1.62
A-3	13.6	0.65	0.04	2.23	0.40	3.23
A-4	13.6	0.60	0.03	2.23	0.21	2.98
B-1	6.8	0.49	0.08	1.43	0.08	1.00
B-2	6.8	0.54	0.02	1.40	0.05	1.06
B-3	13.6	0.59	0.02	1.98	0.23	2.31
B-4	13.6	0.62	0.06	1.85	0.10	2.21
B-5	27.2	0.86	0.18	3.02	0.63	7.84
B-6	27.2	0.95	0.11	3.88	0.26	14.3
B-7	54.4	1.02	0.15	3.67	0.44	13.7
B-8	54.4	0.96	0.11	3.87	0.23	14.4
C-1	6.8	0.57	0.04	1.66	0.15	1.57
C-2	6.8	0.55	0.05	1.76	0.08	1.72
D-1	1.4	0.38	0.01	1.03	0.03	0.4
D-2	2.7	0.43	0.11	1.15	0.17	0.57
D-3	5.4	0.52	0.03	1.49	0.16	0.74
D-4	10.9	0.57	0.04	2.00	0.05	2.28
E-1	-**	0.49	0.23	1.52	0.1	1.13
E-2	-**	0.49	0.02	1.4	0.09	0.96
E-3	-**	0.52	0.3	1.4	0.06	1.02
E-4	-**	0.52	0.03	1.44	0.02	1.08
E-5	-**	0.74	0.04	2.77	0.2	5.68
E-6	-**	0.75	0.02	2.59	0.22	5.03
E-7	-**	0.66	0.04	2.36	0.3	3.68
E-8	-**	0.66	0.02	2.26	0.22	3.37
E-9	-**	0.5	0.02	1.79	0.08	1.6
E-10	-**	0.34	0.05	1.65	0.18	0.93
F	-**	0.37	0.05	1.44	0.13	0.77

* The symbols S_d and S_D represent the standard deviation of the sample data for the apparent depth and diameter of the craters, respectively.

** These tests consisted of the detonation of 155-mm artillery rounds (TNT).



D_a - Apparent depth of crater

R_a - Apparent diameter of crater

Figure 1. Schema of dimensions measured from craters

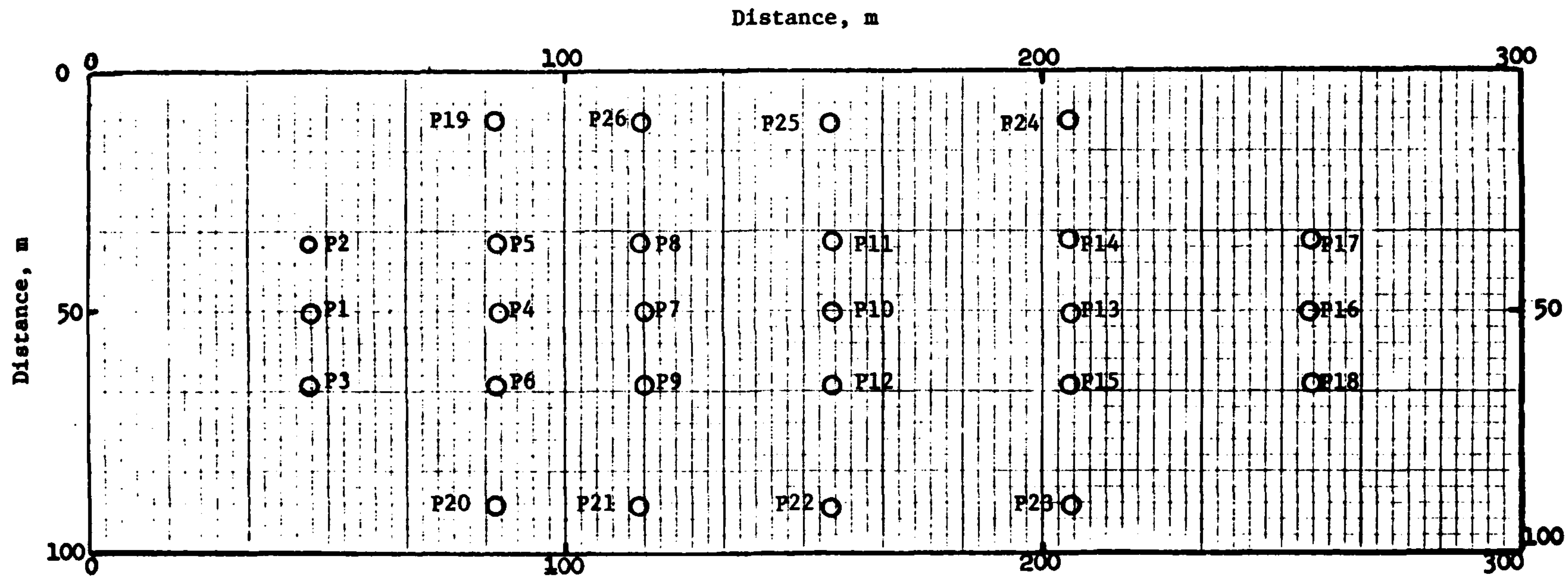


Figure 2. Sample point locations for tests conducted prior to DIRT I exercise

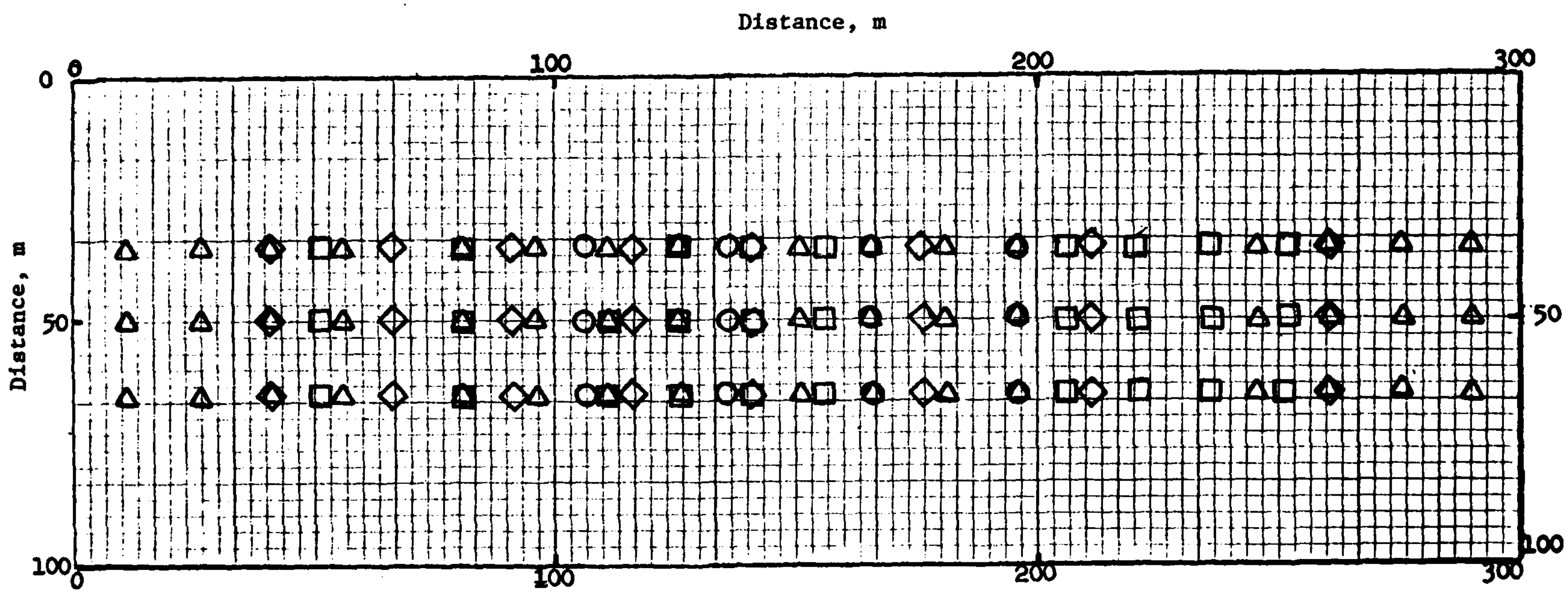


Figure 3. Crater locations for static detonations

Note: The "C" test locations have been deleted from this figure. Refer to Figures 9 and 11 for these locations.

○ – "A" Test

◇ – "B" Test

△ – "D" Test

□ – "E" Test

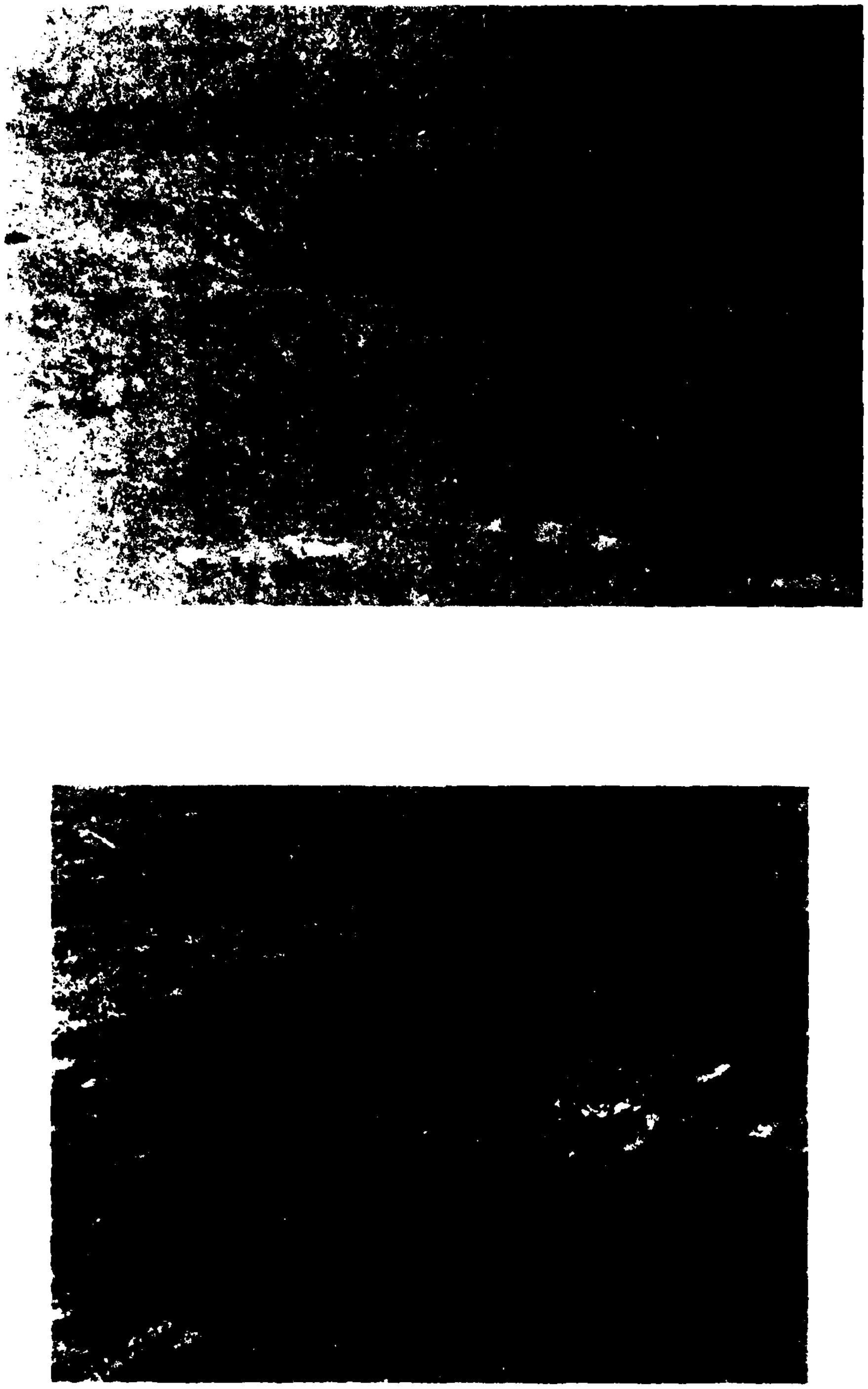


Figure 4. Examples of craters formed by static detonations (top) and dynamic ones

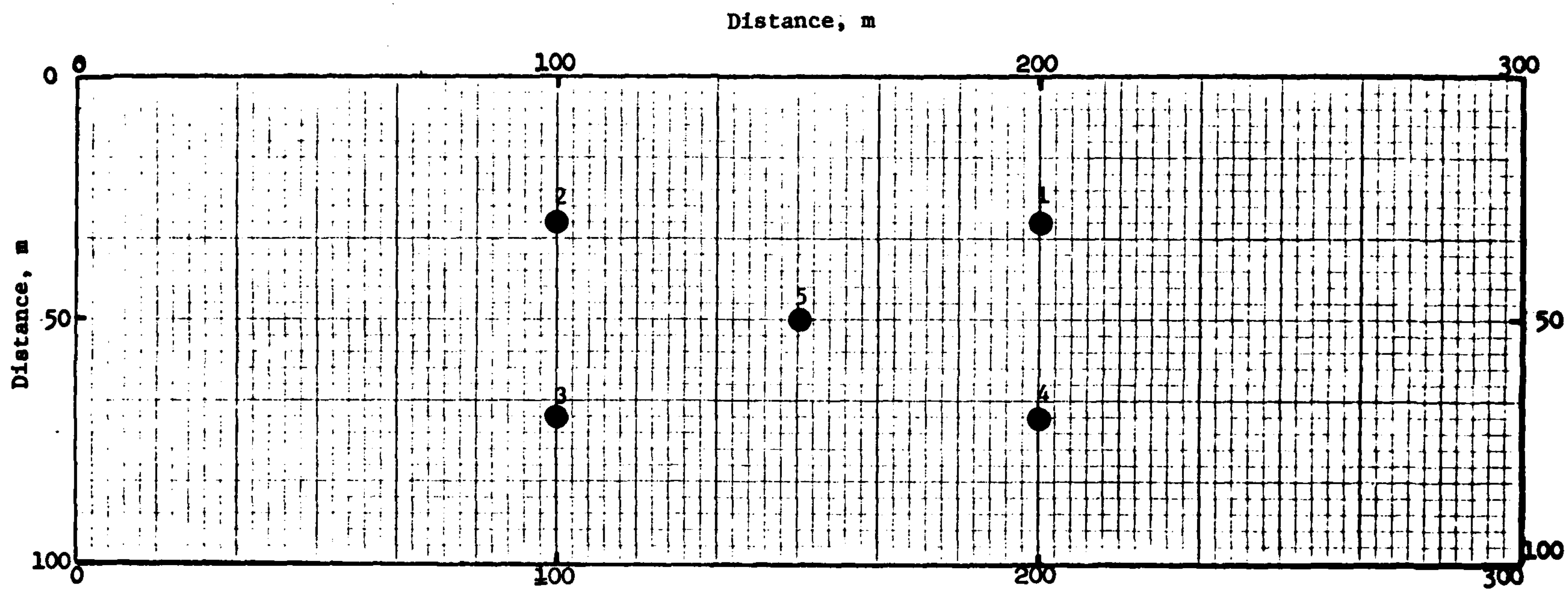


Figure 5. Bulk sample locations

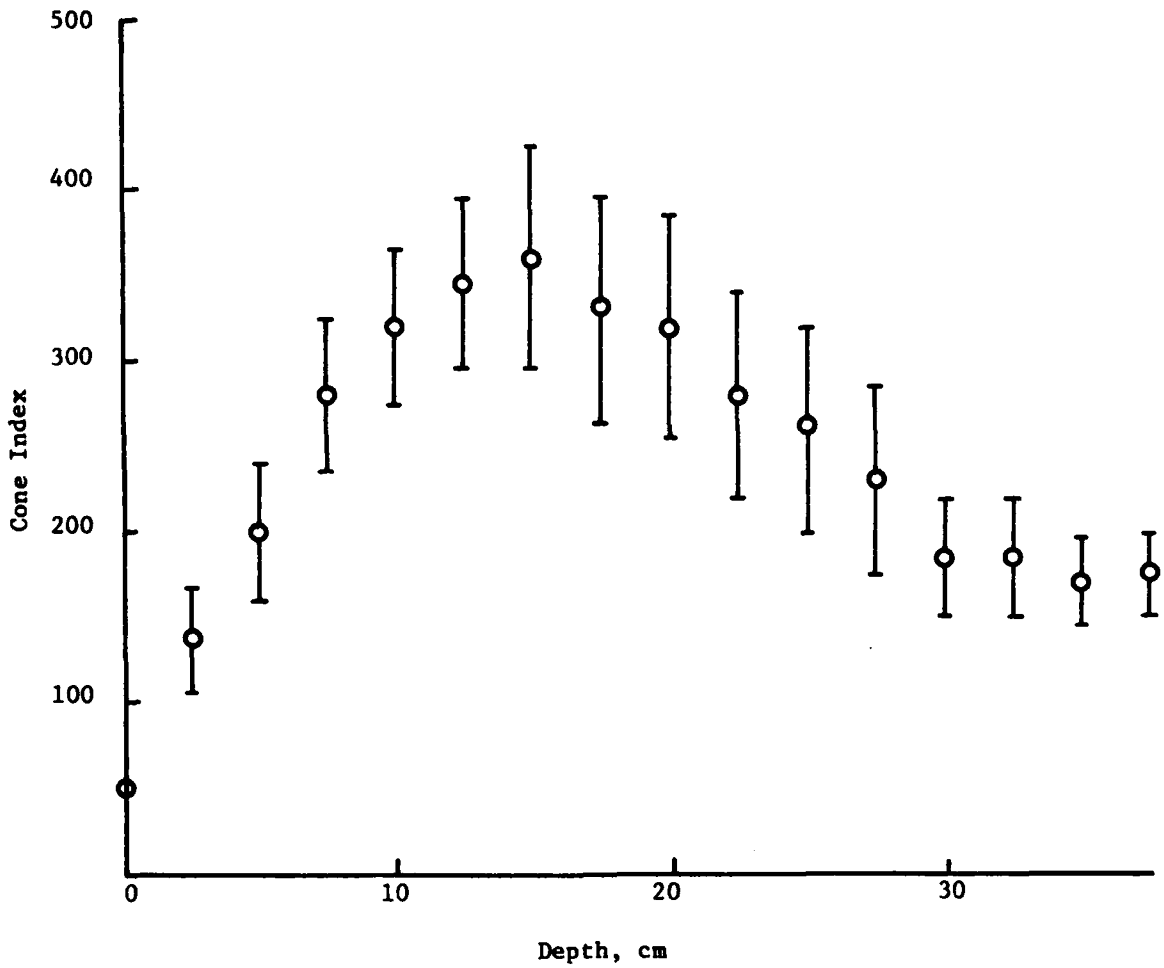


Figure 6. Averaged values of cone index for the P-sample locations

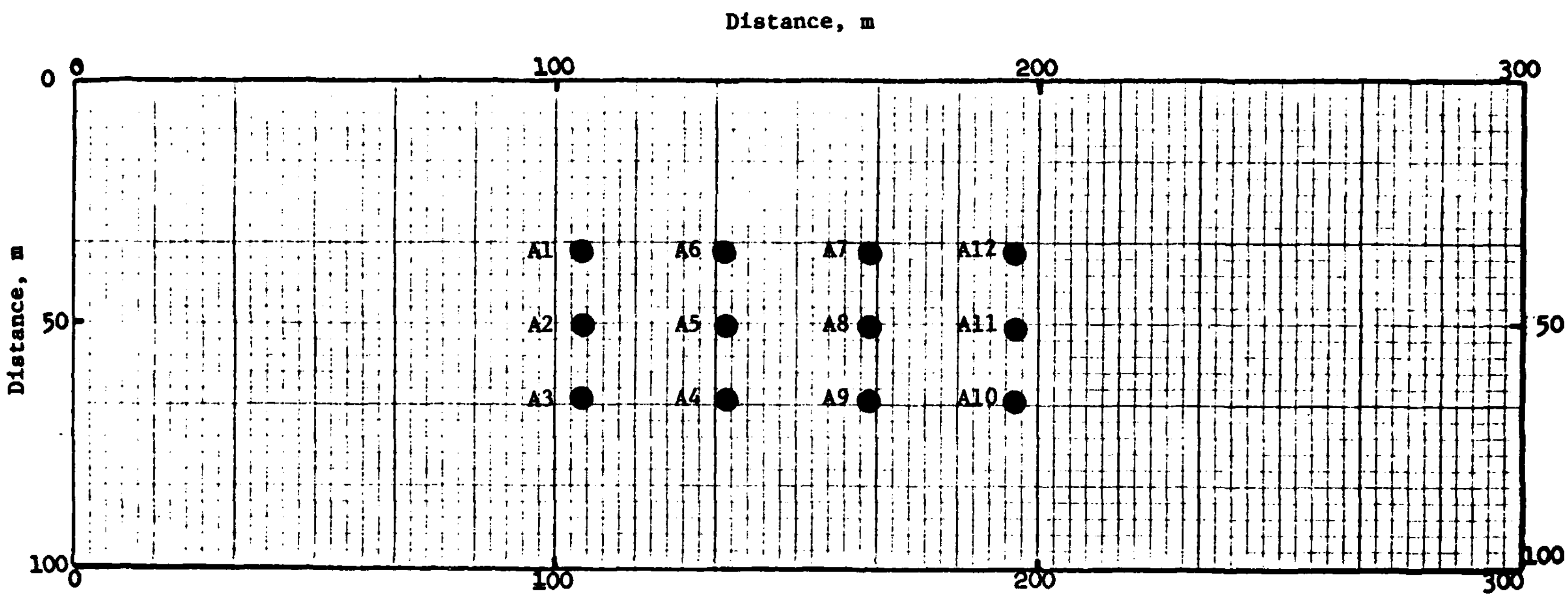


Figure 7. Crater and soil measurement locations for "A" test conducted on 3 October 1978

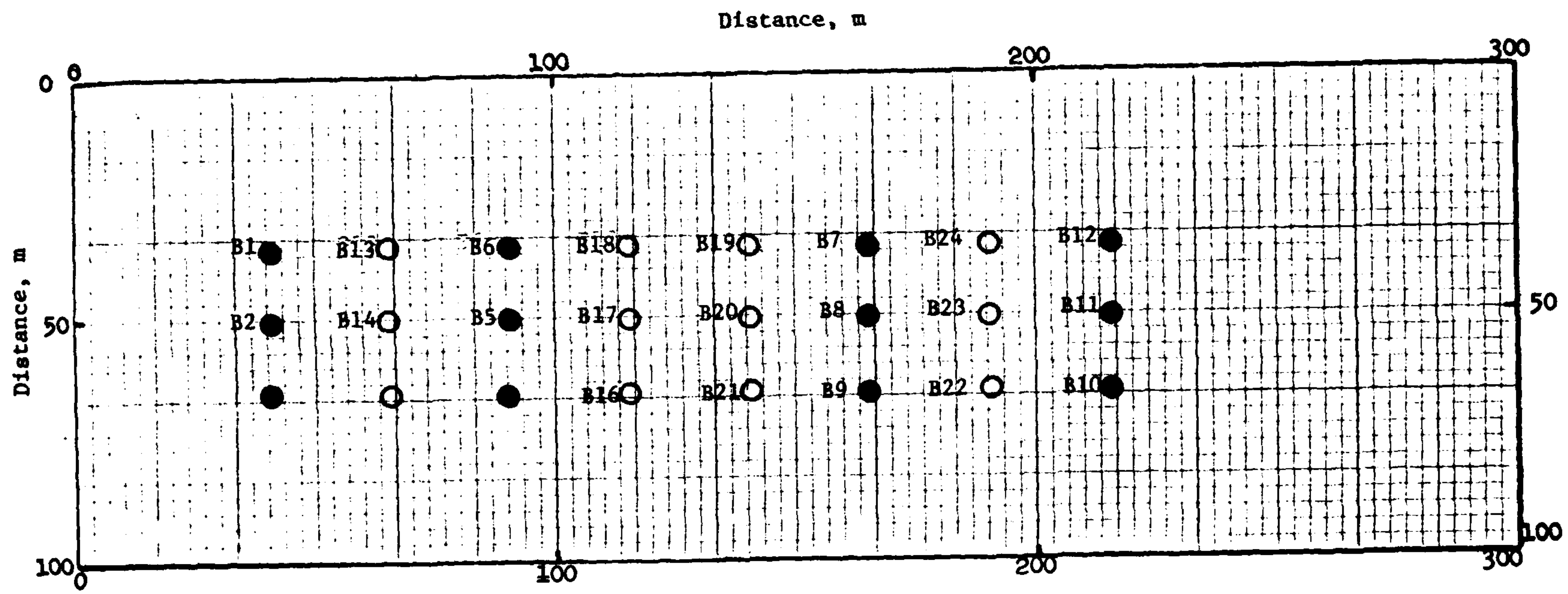


Figure 8. Crater and soil measurement locations for "B" test conducted on 3 October 1978

● – samples taken 3 Oct 78

○ – samples taken 4 Oct 78

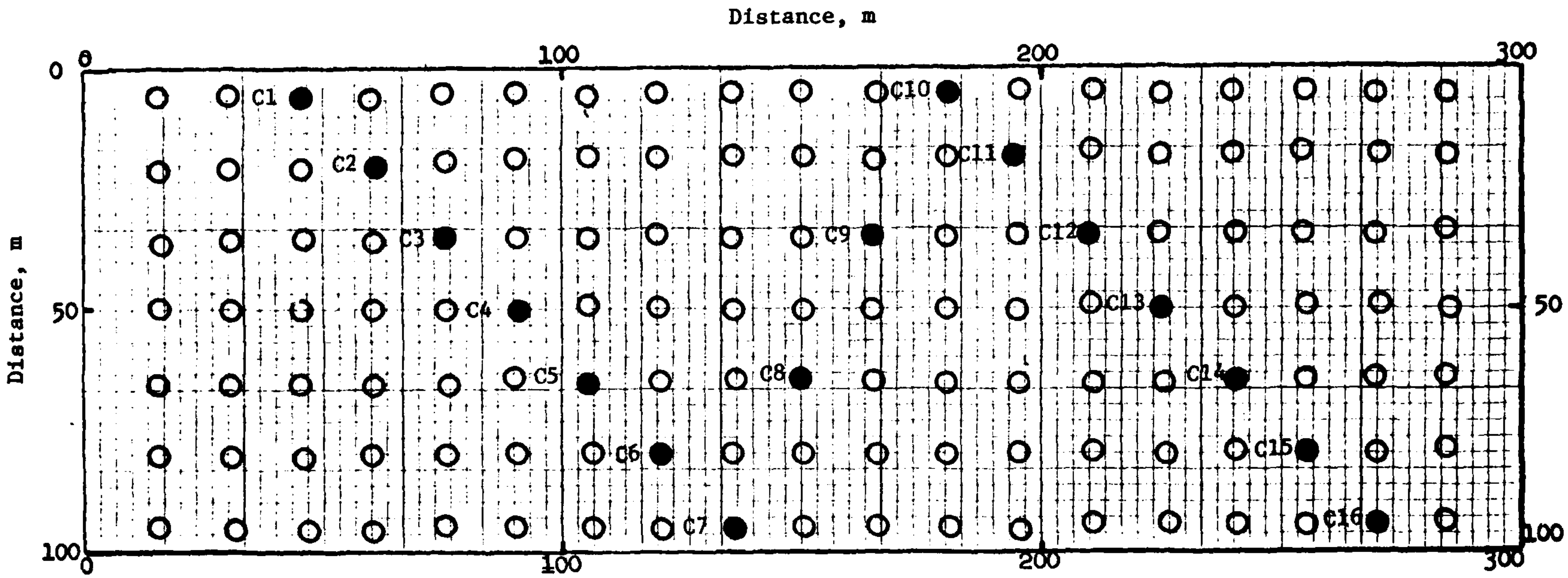


Figure 9. Crater and soil measurement locations for "C" test conducted on 5 Oct 78

○ – crater locations

● – crater soil measurement locations

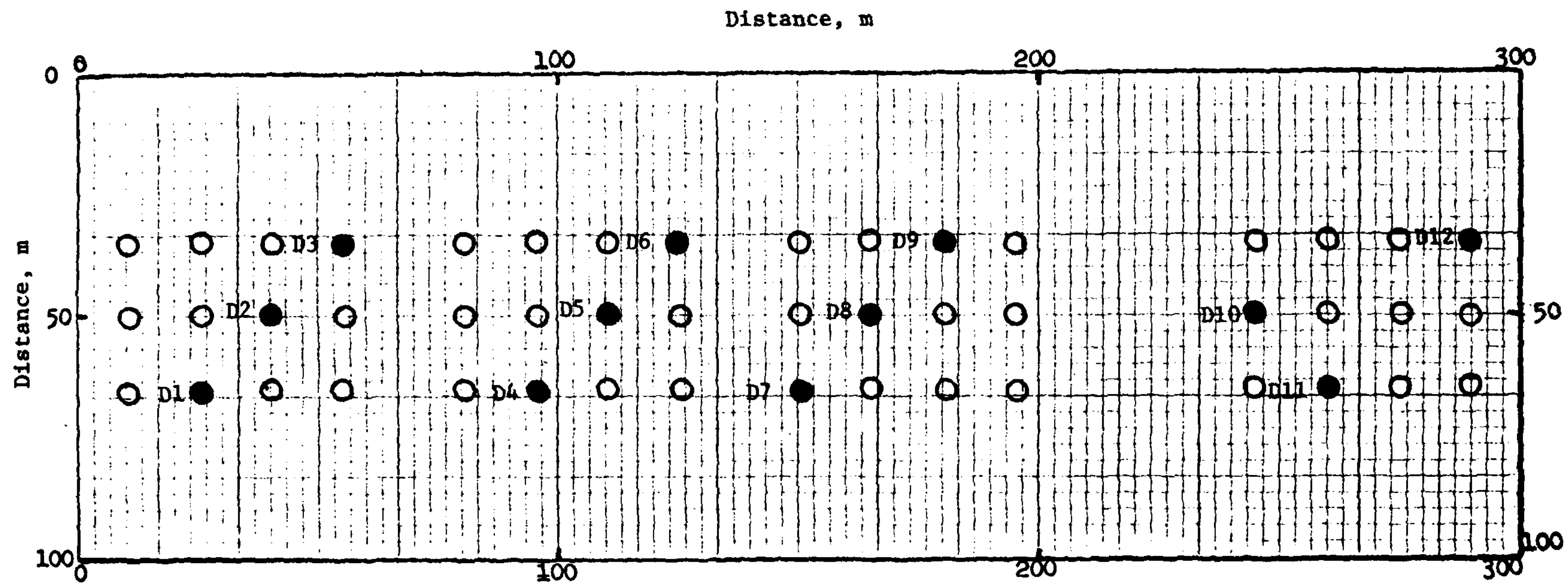


Figure 10. Crater and soil measurement locations for "D" test conducted on 6 Oct 78

○ – crater locations

● – crater and soil measurement location

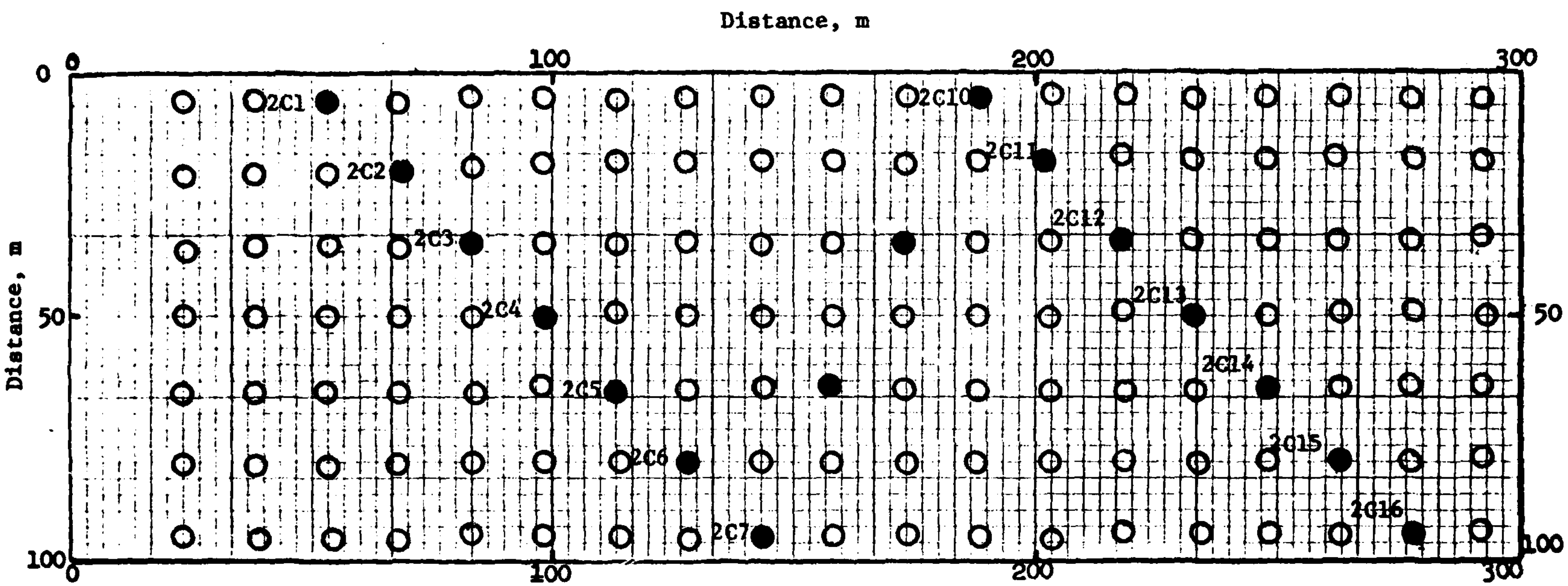


Figure 11. Crater and soil measurement locations for "C" test conducted on 18 Oct 78

○ — crater locations

● — crater and soil measurement locations

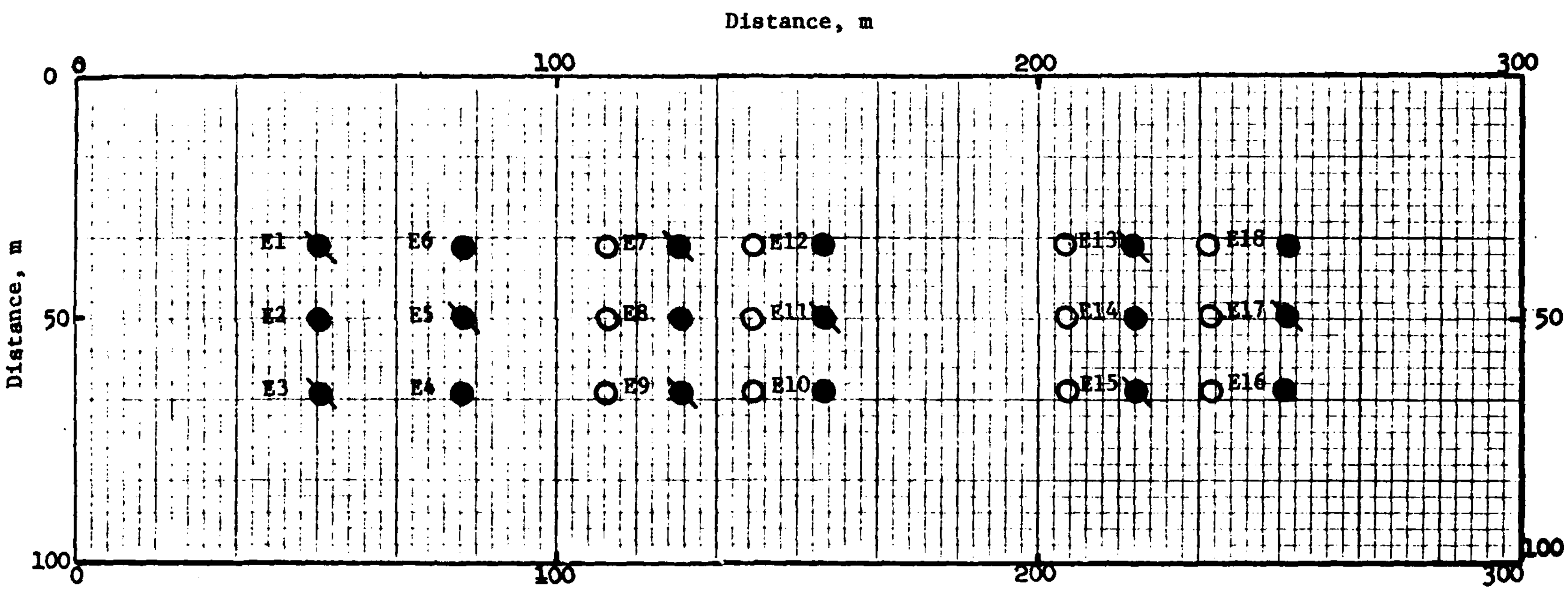


Figure 12. Crater and soil measurement locations for "E" tests conducted on 11 Oct 78

○ — crater locations

● — crater geometry measurement locations

● — crater and soil measurement locations

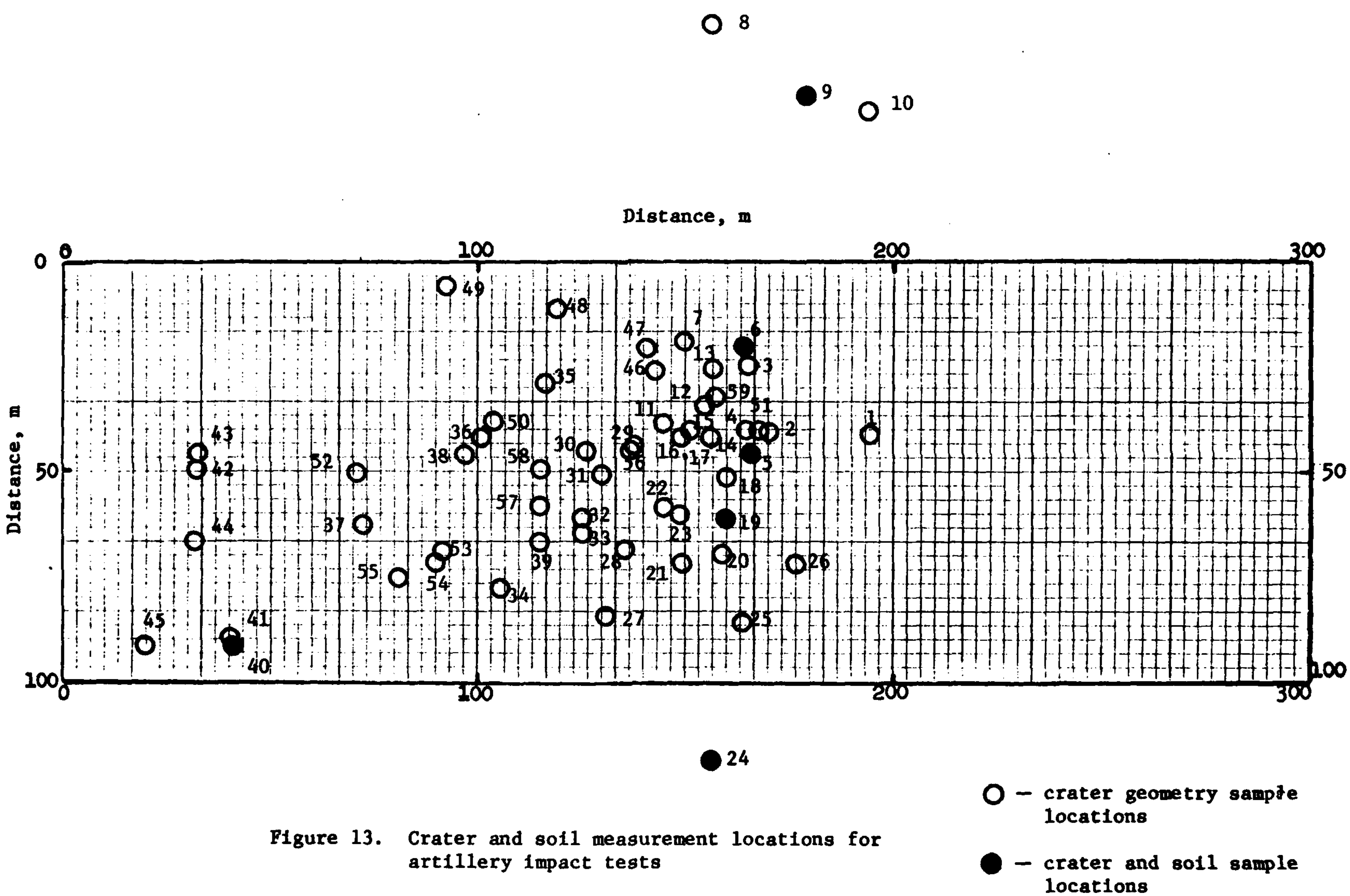


Figure 13. Crater and soil measurement locations for artillery impact tests

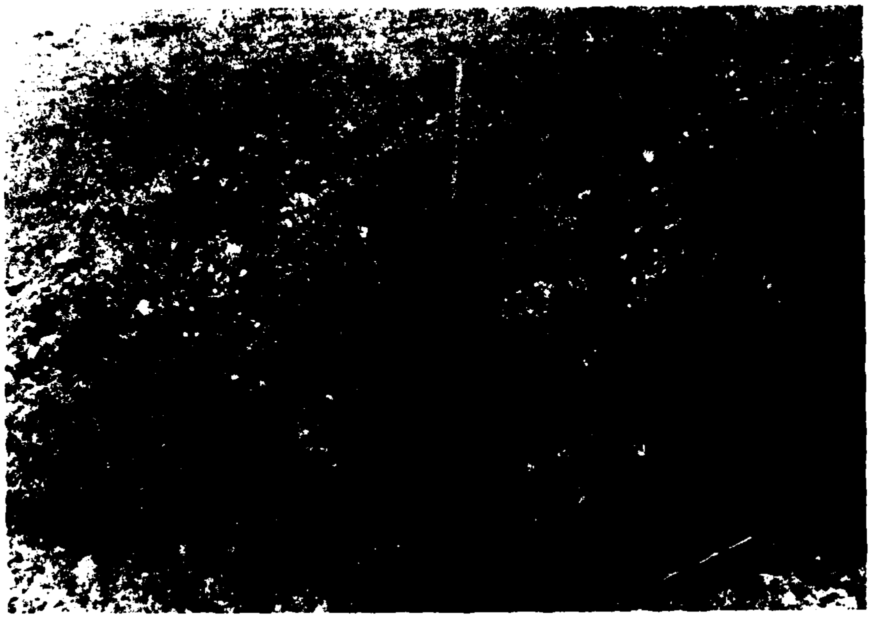


Figure 14. Example of the method of soil moisture sampling for the creater locations

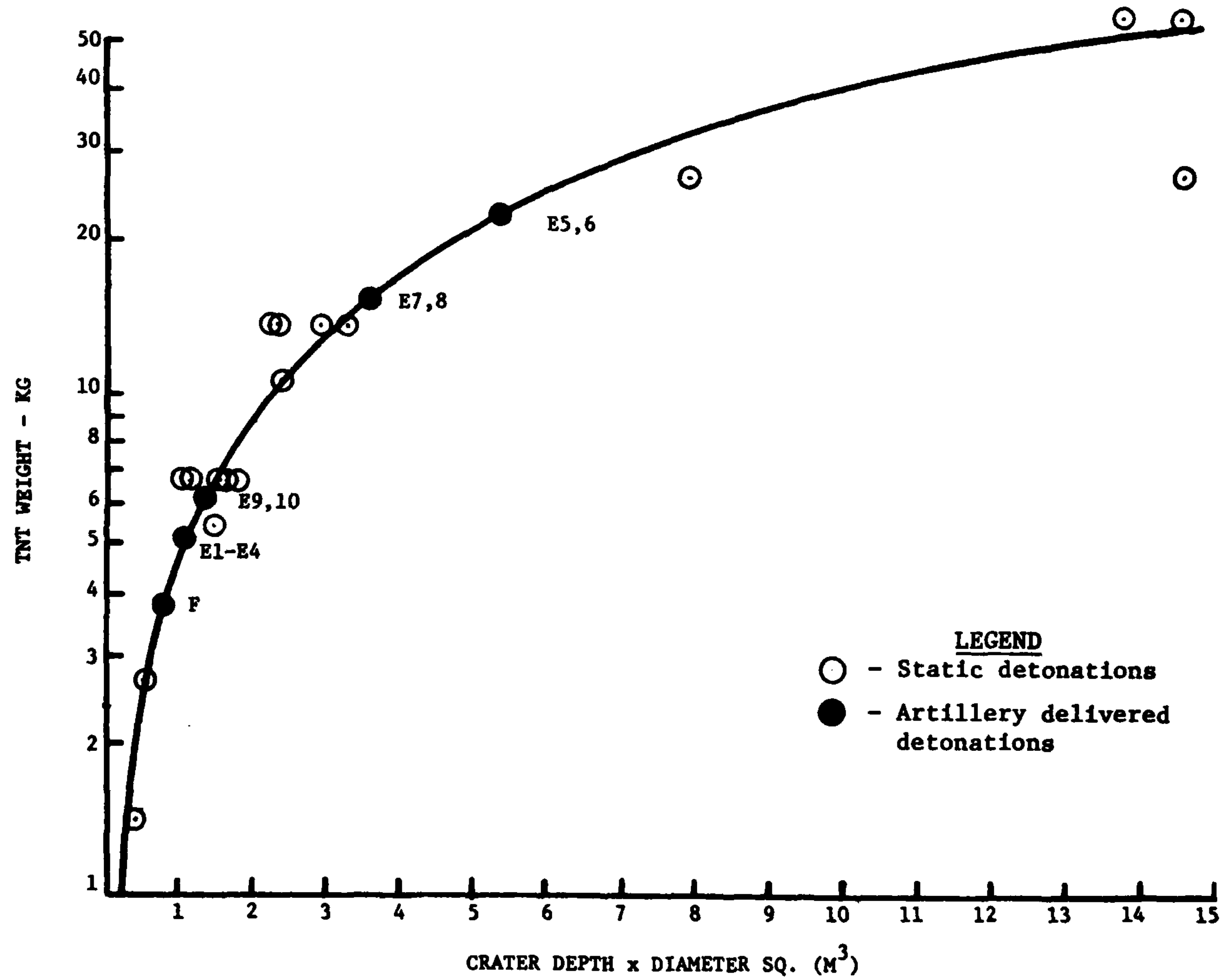
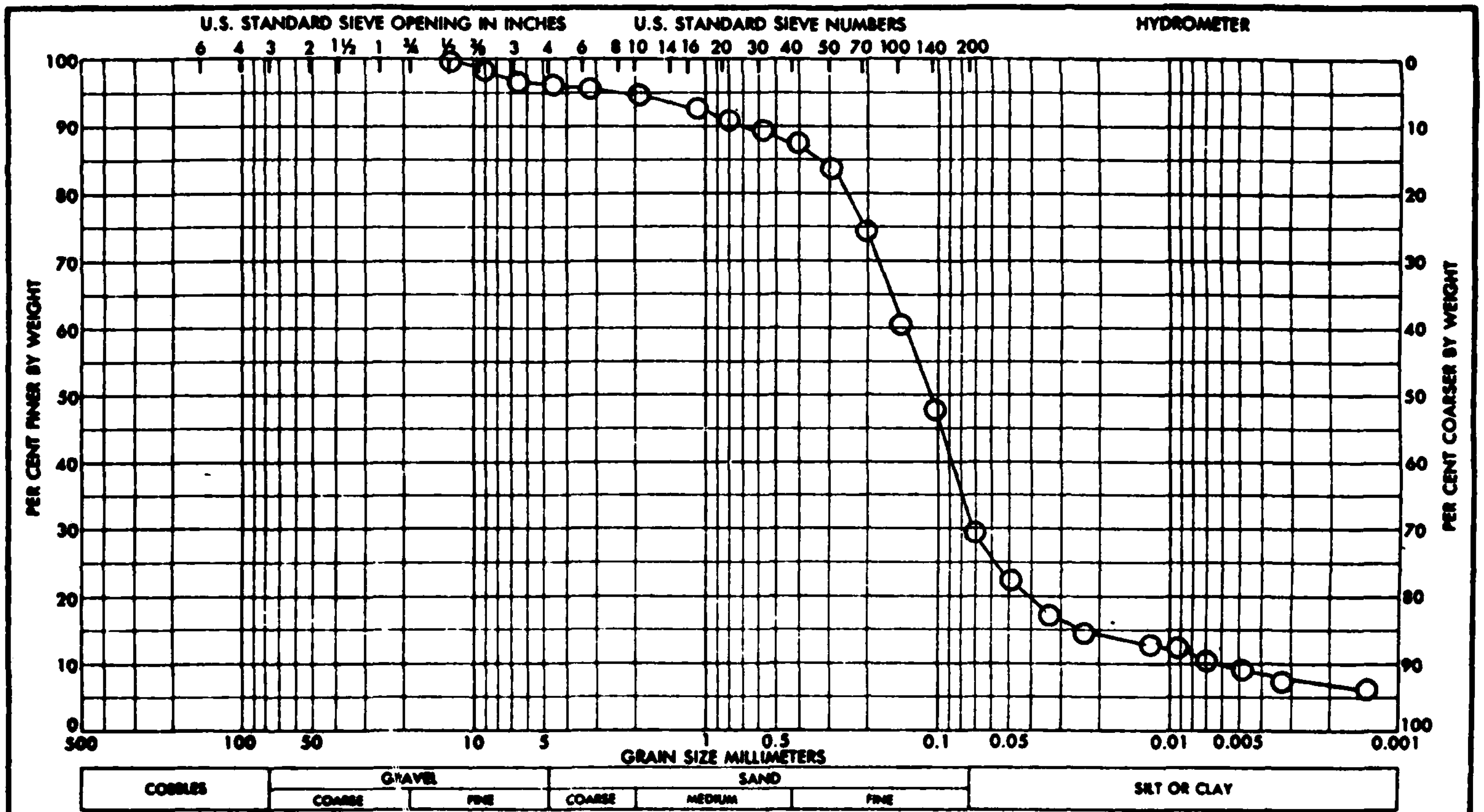


Figure 15. Comparison of crater volume factors (depth x diameter^2) versus explosive charge sizes



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
1	5-45 CM	SILTY SAND (SM), DARK BROWN Gs=2.68 WITH TRACE GRAVEL LOAMY SAND (USDA) ORGANIC CONTENT= 1.4%		NP		

GRADATION CURVES

PROJECT WHITE SANDS MISSILE RANGE

AREA W of ℄ OF PLOT

BORING NO. TEST HOLE NO. 1

DATE 3 NOV 78

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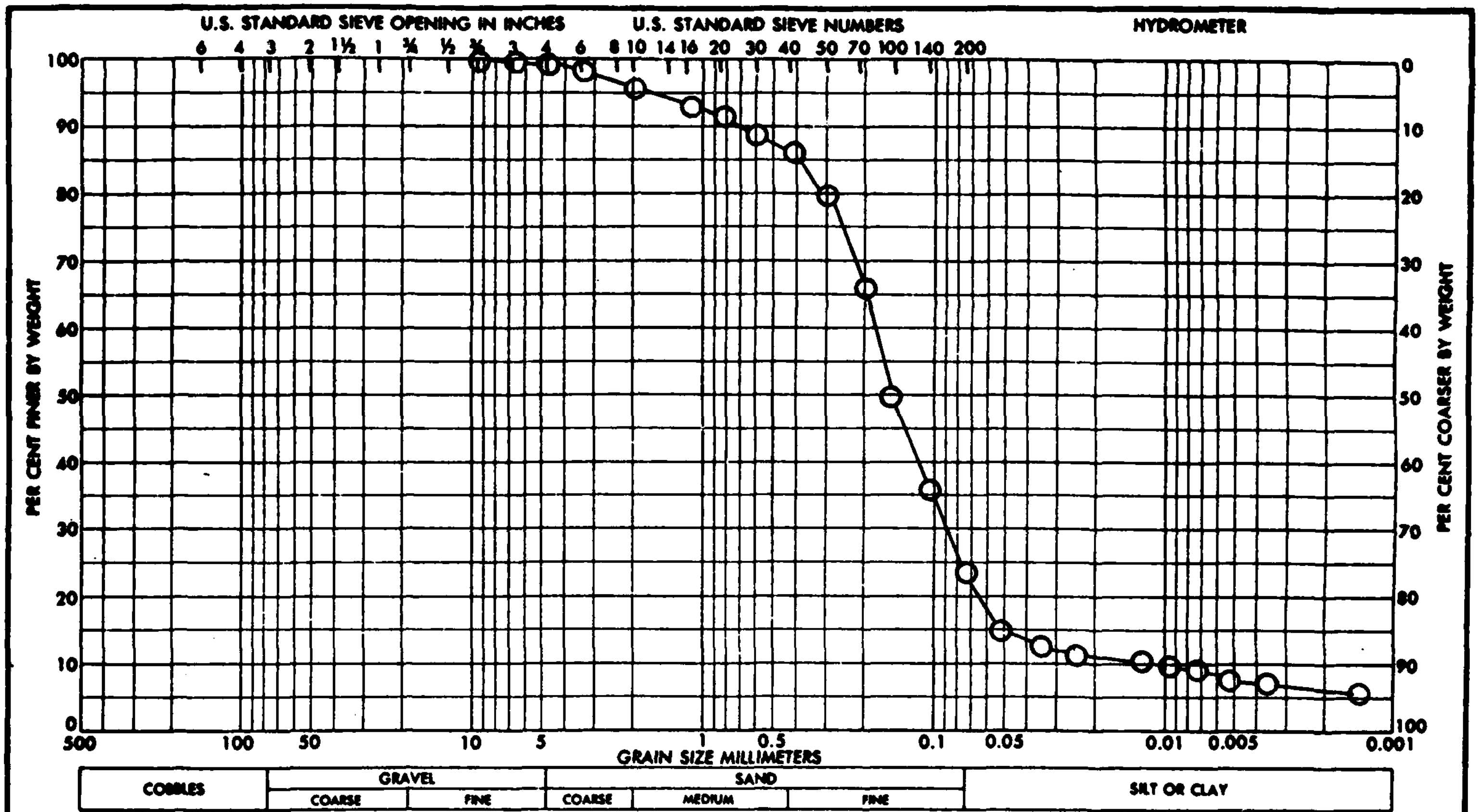
Figure 16. Grain size distribution curve for bulk sample No. 1; Depth = 5-45 cm



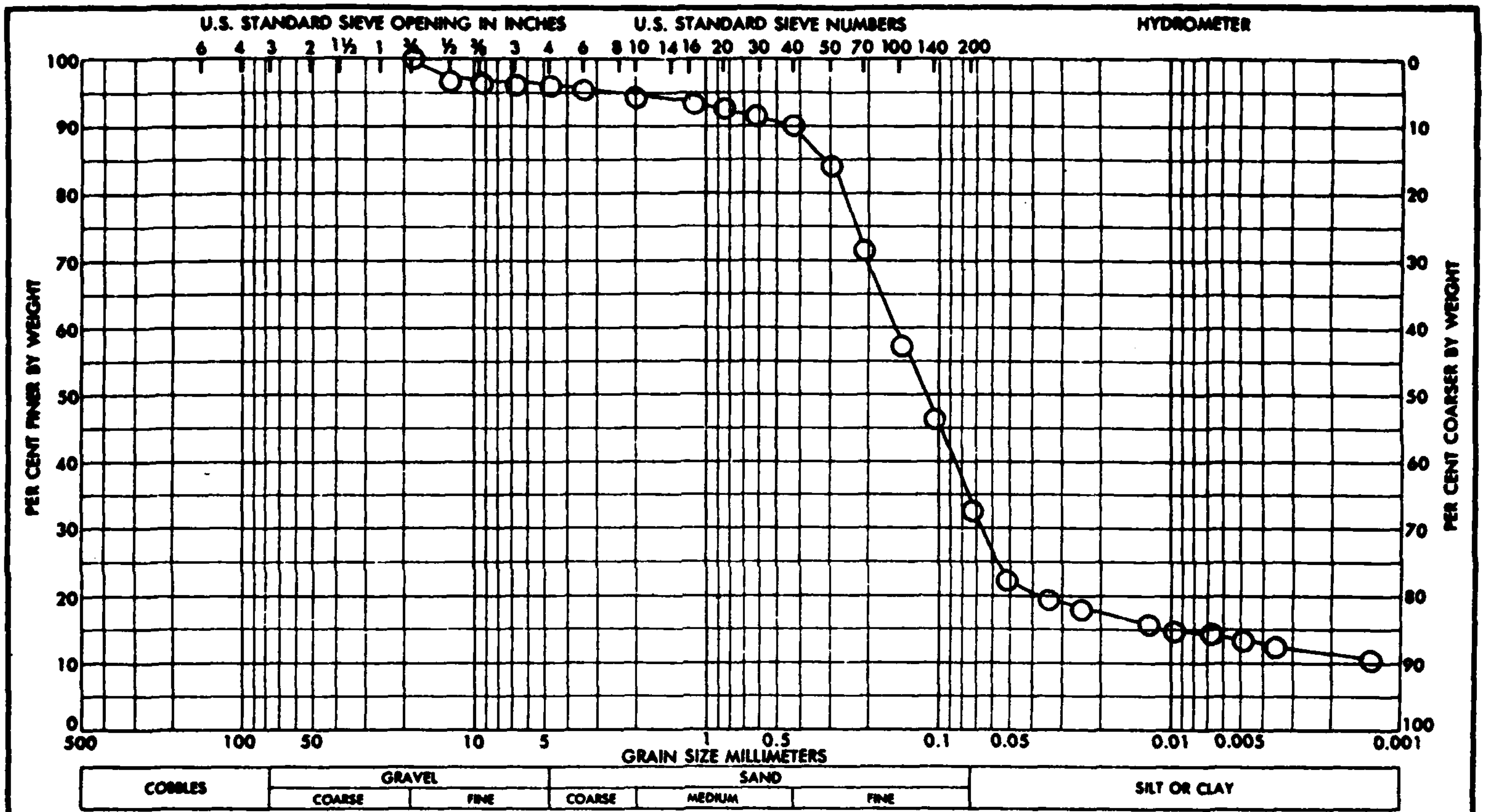
SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
2	75 to 85	SILTY SAND(SM), DARK BROWN Gs = 2.68		NP		
		LOAMY SAND(USDA)				
		ORGANIC CONTENT = 0.6%				

PROJECT	WHITE SANDS MISSILE RANGE
AREA	E of ℄ OF ROAD
BORING NO.	TEST HOLE NO. 1
DATE	3 NOV 78

GRADATION CURVES

U.S. GOVERNMENT PRINTING OFFICE : 1968 O—700-130

Figure 17. Grain size distribution curve for bulk sample No. 1; Depth = 75-85 cm



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
3	5 to 40 CM	SILTY SAND(SM) WITH TRACE GRAVEL, BROWN				
		Gs= 2.70				
		SANDY LOAM(USDA)				
		ORGANIC CONTENT = 0.7%				

PROJECT	WHITE SANDS MISSILE RANGE
AREA	SITE: DIRT I
BORING NO.	TEST HOLE NO. 2
DATE	3 NOV 78

GRADATION CURVES

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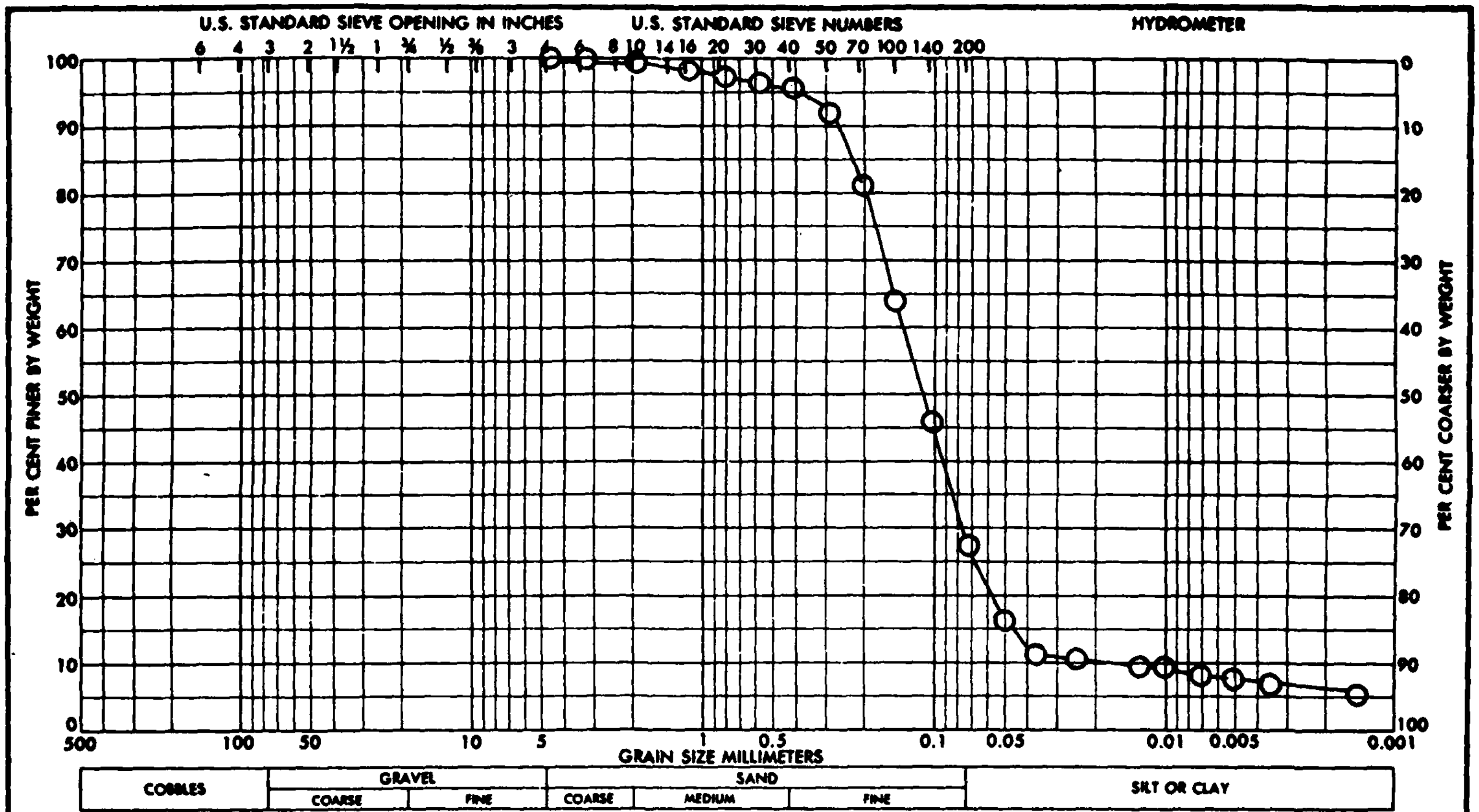
Figure 18. Grain size distribution curve for bulk sample No. 2; Depth = 5-40cm



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
4	75 to 85 CM	SILTY SAND(CM), DARK BROWN Gs= 2.67		NP		
		LOAMY SAND(USDA)				
		ORGANIC CONTENT = 1.8%				

GRADATION CURVES

PROJECT	WHITE SANDS MISSILE RANGE
AREA	E OF ℄
BORING NO.	TEST HOLE NO. 2
DATE	3 NOV 78

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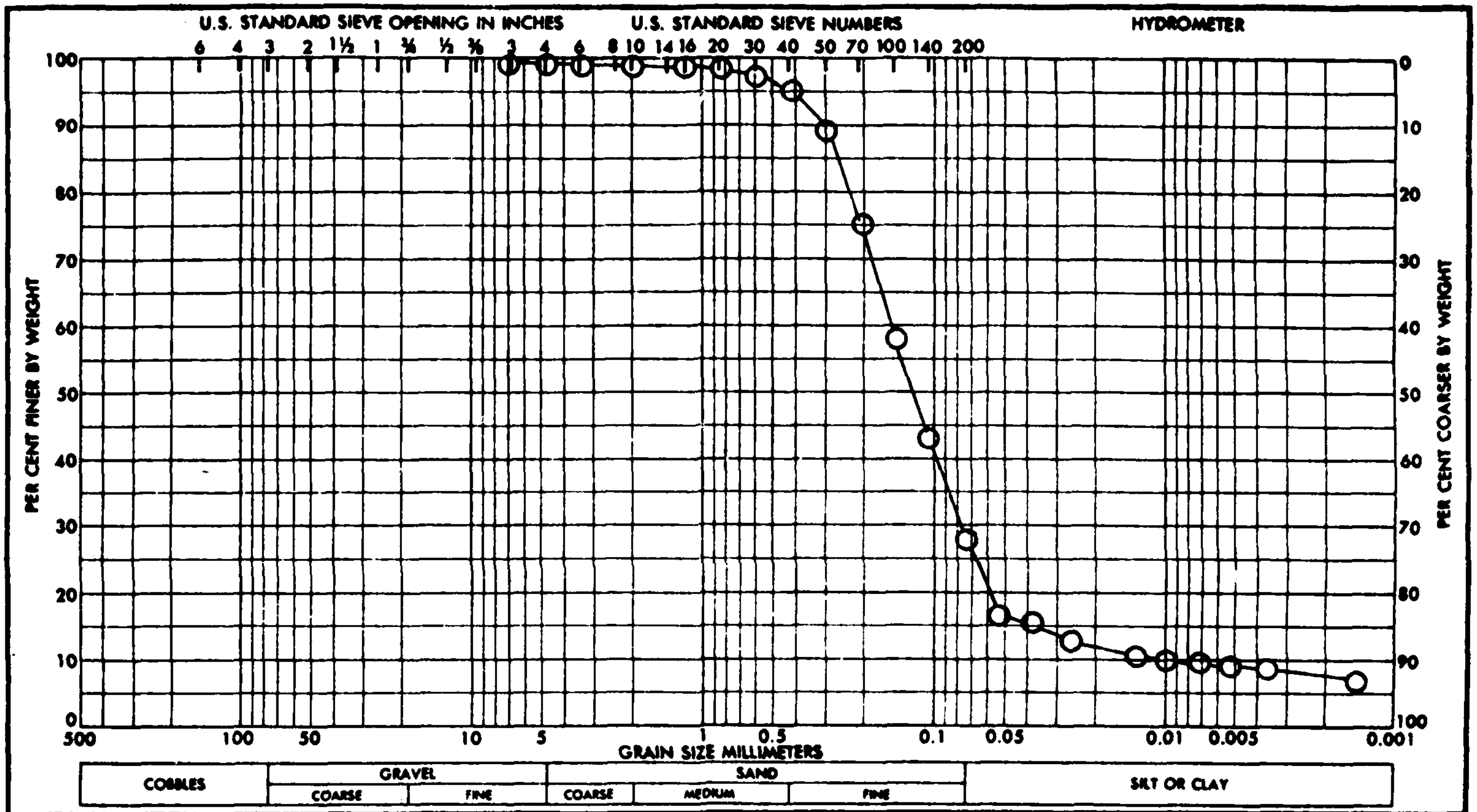
Figure 19. Grain size distribution curve for bulk sample No. 2; Depth = 75-85 cm

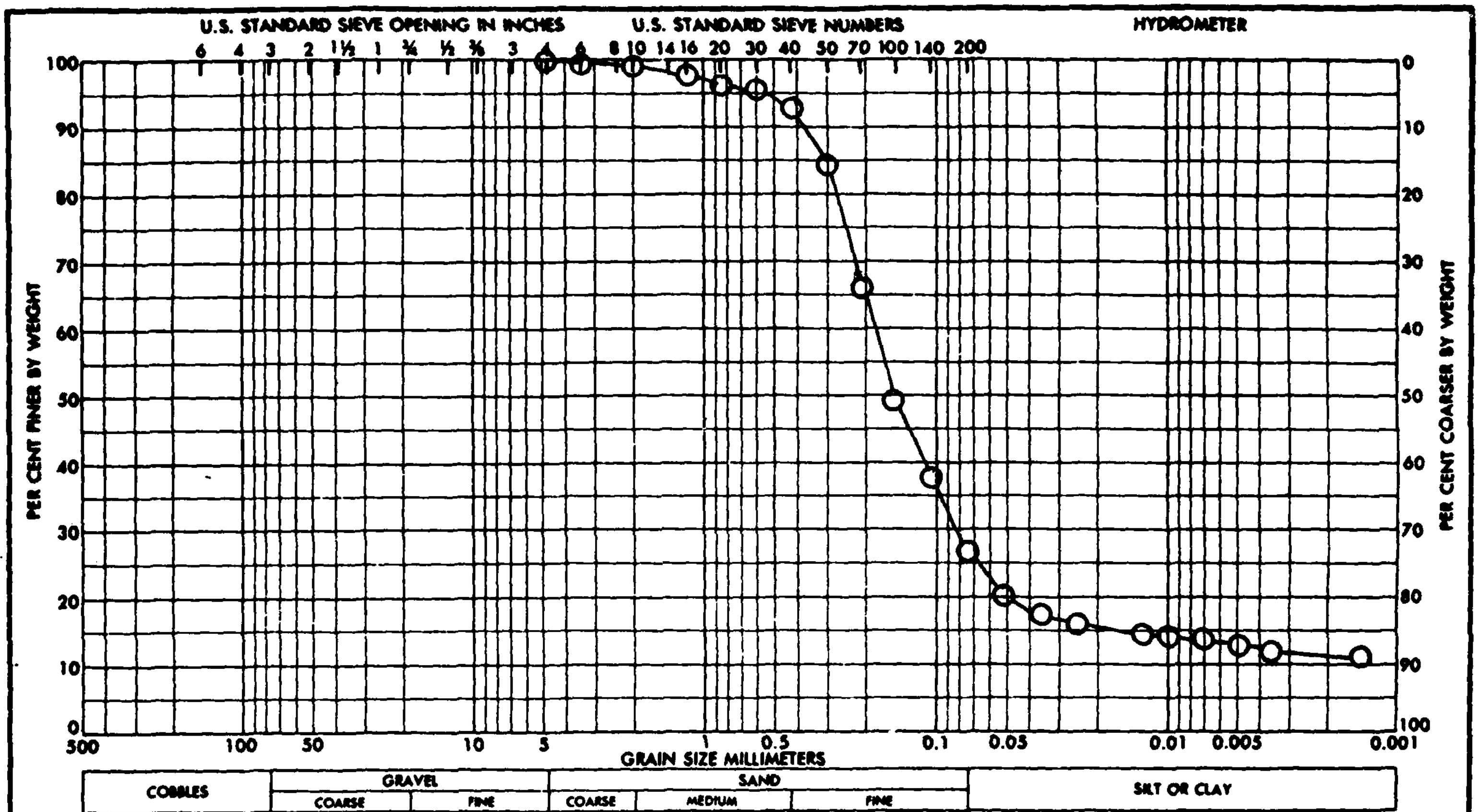


SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
5	5 to 40 CM	SILTY SAND(SM), BROWN		NP		
		Gs= 2.68				
		LOAMY SAND(USDA)				
		ORGANIC CONTENT = 1.5%				

GRADATION CURVES

PROJECT	WHITE SANDS MISSILE RANGE
AREA	W OF ℄ OF PLOT SITE
BORING NO.	TEST HOLE NO. 3
DATE	3 NOV 78

Figure 20. Grain size distribution curve for bulk sample No. 3; Depth = 5-40 cm

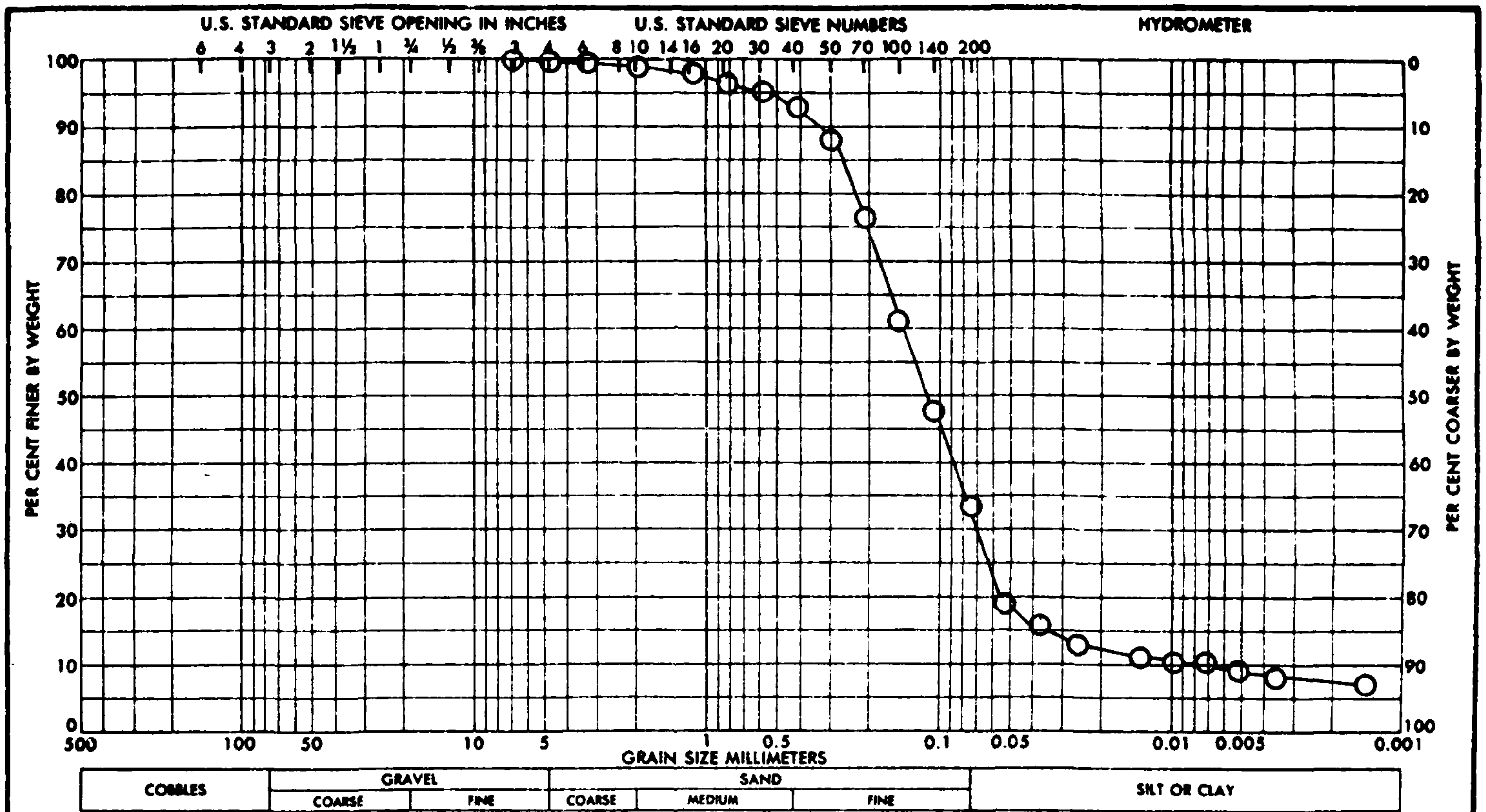


SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
6	85 to 95 CM	SILTY SAND(SM), BROWN		NP		
		Gs = 2.68				
		LOAMY SAND(USDA)				
		ORGANIC CONTENT = 1.6%				

GRADATION CURVES

PROJECT	WHITE SANDS MISSILE RANGE
AREA	W OF ℄ OF PLOT SITE
BORING NO.	TEST HOLE NO. 3
DATE	3 NOV 78

Figure 21. Grain size distribution curve for bulk sample No. 3; Depth = 85-95 cm



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
7	5 to 45 CM	SILTY SAND (SM), DARK		NP		
		BROWN Gs = 2.70				
		LOAMY SAND(USDA)				
		ORGANIC CONTENT = 1.0%				

GRADATION CURVES

PROJECT	WHITE SANDS MISSILE RANGE
AREA	E OF ℄
BORING NO.	TEST HOLE NO. 4
DATE	3 NOV 78

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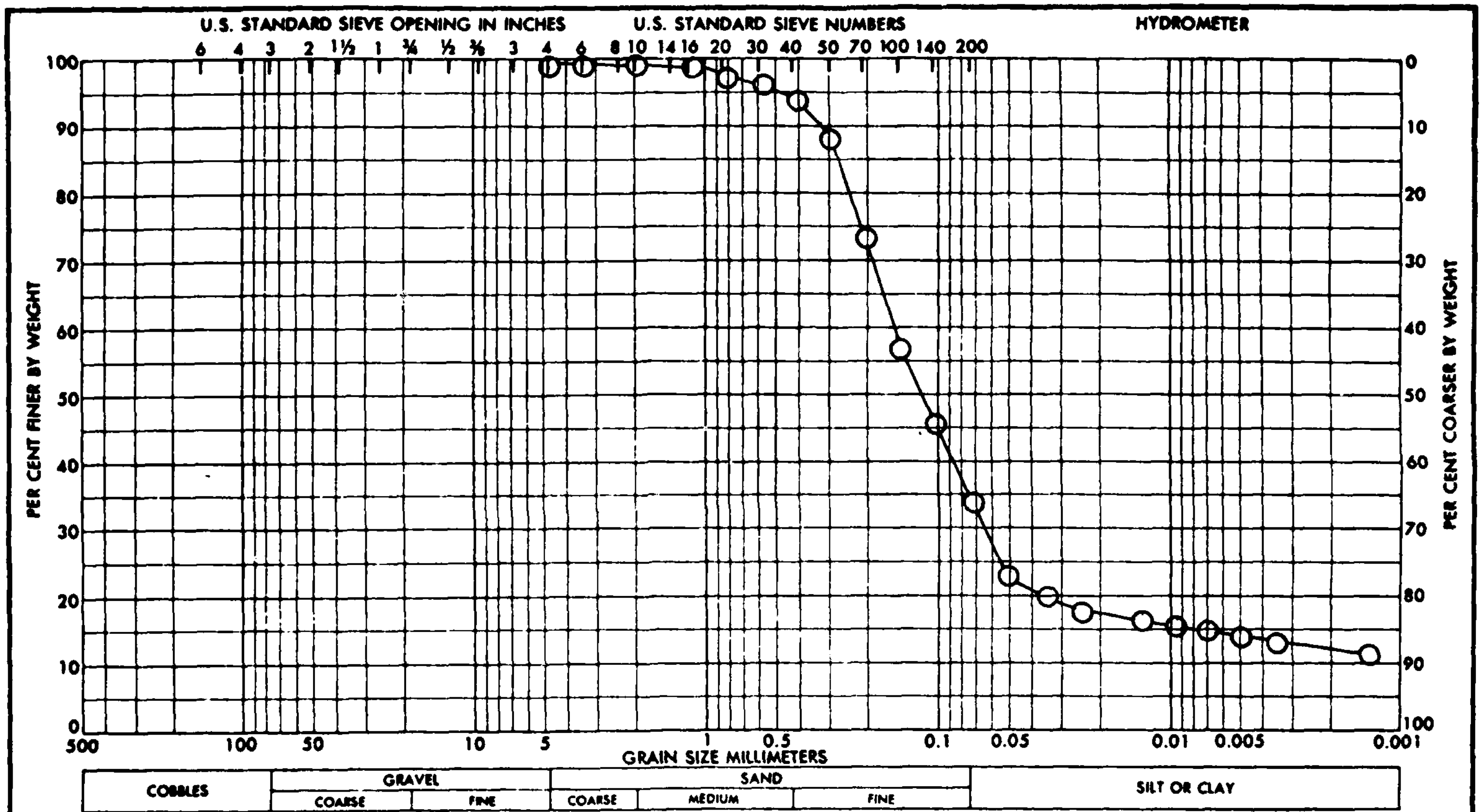
Figure 22. Grain size distribution curve for bulk sample No. 4; Depth = 5-45 cm



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
8	90-100 CM	SILTY SAND(SM), REDDISH BROWN Gs = 2.68		NP		
		ORGANIC CONTENT = 1.2%				

PROJECT WHITE SANDS MISSILE RANGE

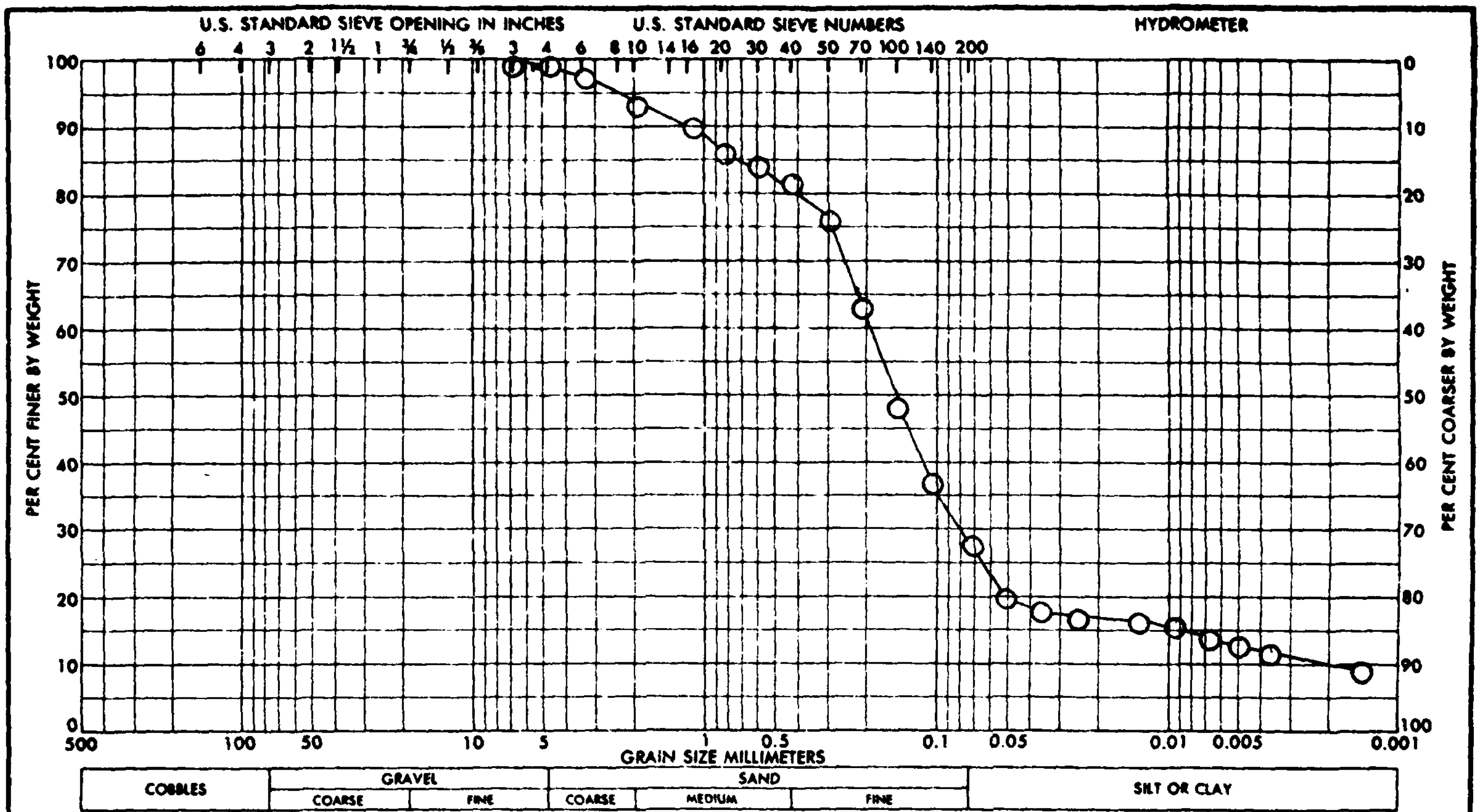
AREA E OF ℄ SITE; DIRT 1

BORING NO. TEST HOLE NO. 4

DATE 3 NOV 78

GRADATION CURVES

Figure 23. Grain size distribution curve for bulk sample No. 4; Depth = 90-100 cm



SAMPLE NO.	ELEV OR DEPTH	CLASSIFICATION	NAT W%	LL	PL	PI
9	5 to 25 CM	SILTY SAND(SM), BROWN		NP		
		Gs= 2.70				
		SANDY LOAM(USDA)				
		ORGANIC CONTENT = 1.2%				

GRADATION CURVES

PROJECT WHITE SANDS MISSILE RANGE

AREA ℄ OF DIRT ROAD

BORING NO. TEST HOLE NO. 5

DATE 3 NOV 78

U.S. GOVERNMENT PRINTING OFFICE : 1963 OF—700-126

Figure 24. Grain size distribution curve for bulk sample No. 5; Depth = 5-25 cm

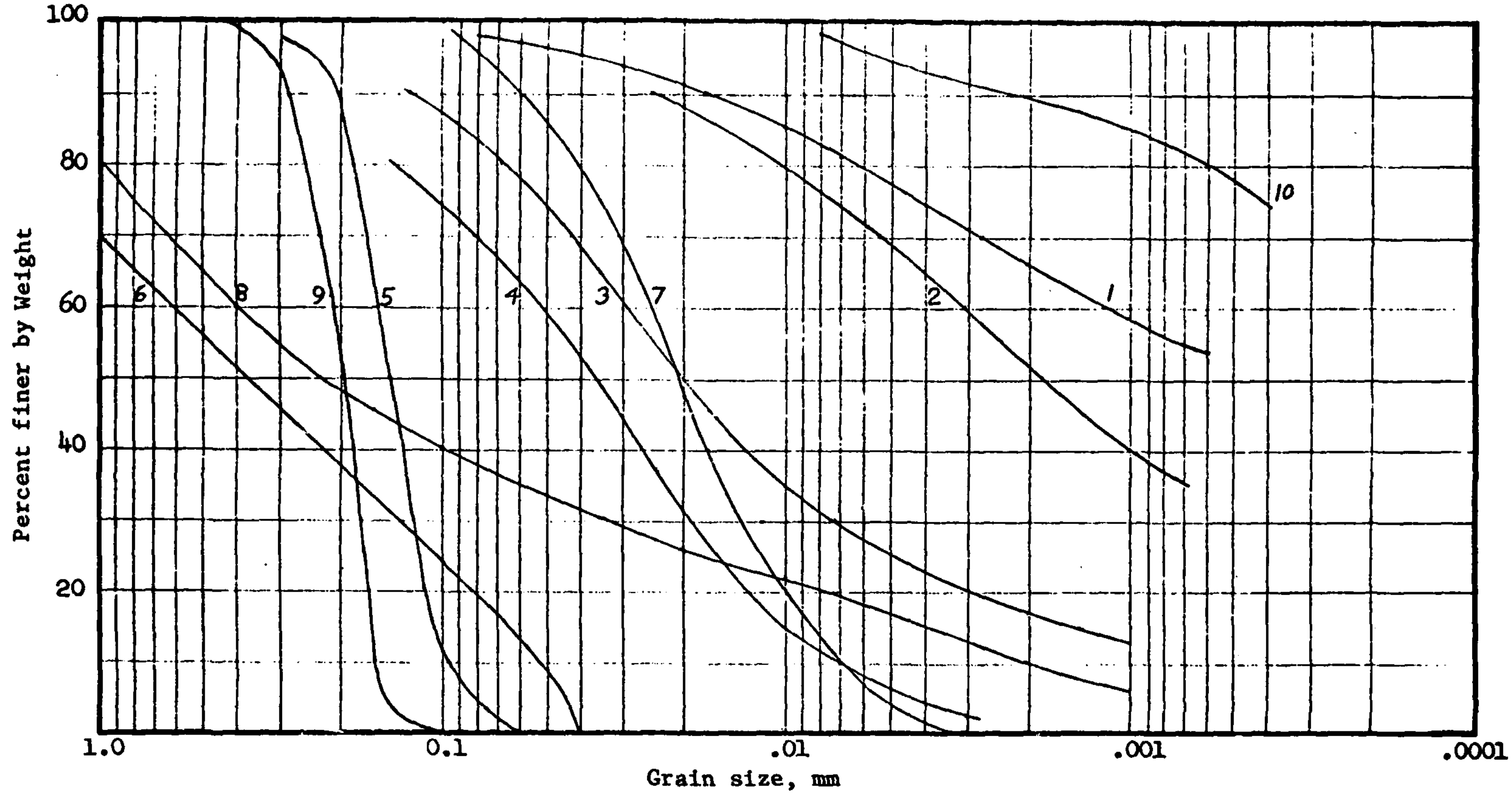


Figure 25. Representative soil grain size distributions (after Tschebotarioff, Soil Mechanics, Foundations and Earth Structures, McGraw-Hill, 1951) showing clays (1, 2) and silts (3, 4) from the Nile delta; beach sand from Port Said (5) and Daytona Beach (9); sand artificially graded for maximum density (6); Vicksburg loess (7); New Mexico adobe (8); and Wyoming bentonite (10).

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Miller, Charles A
Terrain characteristics at DIRT-I test site, White Sands Missile Range, New Mexico / by Charles A. Miller. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
14, [38] p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; EL-79-1)
Prepared for U. S. Army Electronics Research and Development Command, White Sands Missile Range, N. Mex., under Intra-Army Order No. W43P6578-8146.

1. DIRT-I Test Program. 2. Dust clouds. 3. Explosion effects. 4. Soil data. 5. Terrain. 6. Terrain data. 7. White Sands Missile Range, N. M. I. Atmospheric Sciences Laboratory. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; EL-79-1
TA7.W34m no.EL-79-1